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THE
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VOLUME XLI JUNE 1915 NUMBER 5

ANOMALOUS DISPERSION IN THE SUN

By SEBASTIAN ALBRECHT

INTRODUCTION

In recent years, Professor Julius has published a number of articles in which he developed the theory of anomalous dispersion, with special reference and application to solar phenomena. As the writer required, in another line of work, a detailed knowledge of the accidental as well as the systematic errors in Rowland's Table of Solar Spectrum Wave-Lengths, it became necessary, among other things, to test these wave-lengths for possible effects of anomalous dispersion. Before proceeding with the account of that test, the writer will state briefly such of the principal deductions from the anomalous-dispersion theory as will enable the reader to gain at least a partial insight into the causes which, it is supposed, underlie the effects discussed in this article.

By anomalous dispersion is denoted the general property of matter that its refracting power $\pm(n-1)$ varies rapidly as we approach an absorption line. Two of the effects of the property of anomalous dispersion are (*a*) anomalous refraction and (*b*) anomalous scattering. Anomalous dispersion subsists even when the density of the medium is perfectly uniform and the propagation of

light rectilinear. In that case anomalous scattering only is operative. Rayleigh's formula for the coefficient of scattering (s) is

$$s=\frac{32\pi^3(n-1)^2}{3N\lambda^4},$$

where N is the number of scattering particles per unit volume, and λ is the wave-length of the light under consideration. We see that s passes through a sharp maximum in the neighborhood of every λ which corresponds to an absorption line, because there the factor $(n-1)^2$ increases rapidly as we approach the line from either side. Even absolutely monochromatic absorption would thus, in an extensive atmosphere (even with a medium of perfectly uniform density and with rectilinear propagation of light), give rise to a line of a certain width. Every absorption line of a stellar atmosphere is, therefore, enveloped in what is called a dispersion band. It is through asymmetry of the dispersion band that displacements of lines by anomalous dispersion take place, for the true absorption line cannot be displaced by this cause.

More recently Julius[1] has developed an extension of the anomalous-dispersion theory, according to which there must be a mutual influence of Fraunhofer lines. As the position "of a certain line A depends on the refracting power of the medium for the adjacent waves, it must be influenced by the presence of a strong neighboring line B." In other words, Fraunhofer lines which are close to each other exert a mutual influence upon each other. This is one of the ways in which asymmetries are produced in dispersion bands. The theory requires that the influence be opposite in direction in the two cases where the line B lies toward the red or toward the violet of line A, and in addition, that when B lies on the red side of A the influence must be greater than when B lies on the violet side. It is this effect which lends itself most readily to the test proposed, and for convenience the writer will refer to it as the Julius effect. Other effects of anomalous dispersion will not be considered here, and for further details in regard to the theory the reader is referred to the original articles by Julius.

[1] *Astrophysical Journal*, **40**, 1, 1914. (References to earlier articles by Julius will be found here.)

Julius (*op. cit.*) has himself made a test for this effect, using as a basis St. John's measurements of displacements of the Fraunhofer lines at the edges toward center and limb of eccentrically located sun-spots. Julius refers to these displacements in sun-spot spectra as the Evershed effect. His problem was to select from St. John's list such lines as have close companions, either to the red or to the violet, of sufficient strength to produce the anomalous dispersion outlined above. If anomalous dispersion is operative, then the lines thus selected should show respectively a decrease or an increase in the amount of the Evershed effect. Julius obtained results which indicated that this does actually occur.

A more recent rediscussion of the same data led St. John[1] to conclude that no such decrease or increase in the amount of the Evershed effect is shown, though he considered the material to be suitable for a definitive test of the Julius effect.

The present investigation is based upon entirely different and independent data, namely, the wave-lengths of the iron lines in the solar spectrum as given in Rowland's Preliminary Table of Solar Spectrum Wave-Lengths. The problem in this case is to compare Rowland's wave-lengths with wave-lengths obtained in the laboratory, in order to determine whether the wave-lengths of lines having close companions respectively toward the red or toward the violet in the solar spectrum differ systematically from each other and from the lines which are not thus accompanied by close companions.

DESCRIPTION AND TREATMENT OF THE DATA

Table I contains all the lines which were examined for a possible Julius effect. As far as the writer is aware this is the complete list of lines for which the *group* according to pressure displacement is known. The choice of material was restricted to these lines,[2]

[1] *Astrophysical Journal*, **41**, 28, 1915; *Mt. Wilson Contr.*, No. 93.

[2] In the summer of 1914 the writer had investigated this problem without eliminating the pressure effect. In that investigation a much larger list of lines was available, and the results are in fair agreement with those discussed in this article. However, as the pressure displacements according to the Mount Wilson groups are definitely confirmed in these reductions, and as the lines of the several pressure groups are not distributed uniformly along the spectrum nor represented in equal numbers, it is preferable to use only those lines for which the pressure effect can be eliminated.

TABLE I

FOR THE DETERMINATION OF THE RELATION BETWEEN THE ROWLAND AND THE INTERNATIONAL SYSTEMS—FOR Fe

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland−I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	[Rowland−I.A.] $\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion: Line); Separation; Etc.
3609.008	.860	*b* 1	+.148	+.148½	3:20, 0.38A to vi.; 5:20, 0.46 to red
18.919	.769	*b* 1	.150	.151	3:20, 0.39 and 3:20, 0.48 to vi.; 8:20, 0.62 to red
31.605	.464	*b* 1	.141	.142	Relatively faint lines on each side
47.988	.845	*b* 1	.143	.144	4:12, 0.43 to vi.
80.069	.915	*a* 1	.154	.154½	2:9, 0.25 to vi.; 2:9, 0.46 to red
87.610	.458	*b* 1	.152	.153	3:6, 0.38 to vi.; 4:6, 0.19 to red
3705.708	.567	*a* 1	.141	.141½	2:9, 0.14 to red
09.389	.250	*b* 1	.139	.140	Companions 1:8 on each side
20.084	.938	*a* 1	.146	.147	Intensity 40. No companion
22.729	.565	*a* 1	.164	.164½	3:6, 0.09 to vi.
27.778	.622	*b* 1	.156	.157	Faint lines on each side. Indeterminate
33.469	.319	*a* 1	.150	.150½	Faint lines on each side. Probably neutral
35.014	.869	*b* 1	.145	.146	4:40, 0.47 to red
37.281	.135	*a* 1	.146	.147	5:30, 0.22, and 3:30, 0.32 to vi.
43.508	.364	*b* 1	.144	.145	2:6, 0.12 to red
45.717	.563	*a* 1	.154	.154½	2:8, 0.23 to vi.; 6:8, 0.34 to red. Indeterminate
46.058	.900	*a* 1	.158	.158½	8:6, 0.34 to vi.
48.408	.264	*a* 1	.144	.144½	Only 1:10 on each side
48.650	.492	*b* 1	.158	.158½	10:1, 0.24 to vi.
58.375	.234	*b* 1	.141	.142½	4:15, 0.55 to vi. Probably neutral
63.945	.792	*b* 1	.153	.154	Only 1:10 on each side
65.689	.541	*b* 1	.148	.149	1:6, 0.16 to red. Relatively weak
67.341	.194	*b* 1	.147	.148	Only 1:8 on each side
88.046	.880	*b* 1	.166	.167	No companion
95.147	.004	*b* 1	.143	.144	Only 1:8 on each side
3815.987	.844	*b* 1	.143	.144½	3:15, 0.5 to red
26.027	.886	*b* 1	.141	.142½	No relatively strong companions
27.980	.826	*b* 1	.154	.155	Faint companion on each side
34.364	.227	*b* 1	.137	.138	4:10, 0.14 to red; 3:10, 0.36 to vi.
86.434	.287	*a* 1	.147	.147½	3:15, 0.51 to red
87.196	.053	*b* 1	.143	.144½	3:7, 0.25 to vi.
88.671	.520	*b* 1	.151	.152	2:5, 0.11 to vi.; 2:5, 0.30 to red
95.803	.659	*a* 1	.144	.144½	3:7, 0.22 to vi.
99.850	.711	*a* 1	.139	.139½	No close companion
3903.090	.950	*b* 1	.140	.141½	2:10, 0.32 to vi.; 2:10, 0.31 to red
06.628	.482	*a* 1	.146	.146½	2:10, 0.19 to vi.; 4:10, 0.26 to red
20.410	.261	*a* 1	.149	.149½	Only 1:10 on each side
23.054	.917	*a* 1	.137	.137½	Only 1:12 on each side
28.075	.925	*a* 1	.150	.151	1:08, 0.14 to vi.; 2:8, 0.16 to red; 2:8, 0.28 to red. Somewhat indeterminate
30.450	.304	*a* 1	.146	.147	2:8, 0.43 to vi. Relatively faint for separation

TABLE I—*Continued*

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion: Line); Separation; Etc.
3956.819	.682	*b* 4	.137	.138	Strong lines on each side. Indeterminate
69.413	.263	*b* 1	.150	.151½	6:10, 0.53 to vi.; 2:10, 0.49 to red. 700:10, 0.79 to vi.
77.891	.746	*b* 4	.145	.146	No close companion
97.547	.398	*b* 4	.149	.150	1:4, 0.29 and 2:4, 0.43 to vi.; 2:4, 0.09 to red
4005.408	.250	*b* 1	.158	.159	Faint lines on each side; and 3:7, 0.45 to red
45.975	.822	*b* 1	.153	.154½	Intensity 30. Only relatively faint lines near
63.759	.604	*b* 1	.155	.156	4:20, 0.32 to vi. Relatively faint
71.908	.748	*b* 1	.160	.161	Only very faint lines near
4132.235	.063	*b* 1	.172	.173½	2:10, 0.14 to vi.; 3:10, 0.46 to red
34.840	.685	*b* 4	.155	.156½	3:5, 0.25 to vi.; 3:5, 0.35 to vi.
44.038	.873	*b* 1	.165	.167	4:15, 0.47 and 2:15, 0.37 to vi.
47.836	.676	*a* or *b*	.160	.161	2:4, 0.33 and 1:4, 0.19 to vi.
91.595	.443	*a* or *b*	.152	.153	3:6, 0.25 to red
91.843	.678½	*e*	.164½	.161	6:3, 0.25 to vi.
4202.198	.032	*b* 1	.166	.167½	1:8, 0.33 to vi.
04.101	.986	*b* 3	.115	.116	4:3, 0.06 to red; 2:3, 0.37 to vi.
10.494	.360½	*c* 5	.133½	.137	3:4, 0.07 to red; 1:4, 0.51 to vi.
16.351	.186	*b* 3	.165	.166	5:3, 0.65 to vi.; and faint lines on each side. Neutral
27.606	.444½	*d* 5	.161½	.168½	20:4, 0.70 to vi.; 1:4, 0.13 to vi.
33.772	.615	*d* 5	.157	.163	4:6, 0.44 to vi.
36.112	.950	*d* 5	.162	.168	Only lines 1:8 near
47.591	.443	*e*?	.148	.144	5:4, 0.60 to vi.; 1:4, 0.13 to vi. Group uncertain
50.287	.133	*c* 5	.154	.160	8:8, 0.66 to red; 2:8, 0.49 to vi.
50.945	.791½	*b* 2	.153½	.155	8:8, 0.66 to vi.
60.640	.487	*c* 2	.153	.156	3:10, 0.36 and 2:10, 0.49 to vi. Indeterminate?
71.934	.764	*b* 1	.170	.171½	6:15, 0.61 to vi.
82.565	.408	*b* 1	.157	.158	2:5, 0.44 to vi.; 4:5, 0.60 to red
91.630	.472	*a*	.158	.159	2:2, 0.35 and 1:2, 0.26 to vi.
94.301	.131½	*b* 2	.169½	.171	2:5, 0.10 to vi.
99.410	.251	*d* 5	.159	.165	3:4, 0.26 to vi.; 2:4, 0.39 to red
4308.081	.909	*b* 1	.172	.173	3:6, 0.17 and 2:6, 0.36 to vi.; 1:6, 0.25 to red
15.262	.089	*b* 3	.173	.174	3:4, 0.12 to vi.
25.939	.768	*b* 1	.171	.172	1:8 on each side. Neutral
37.216	.052	*b* 3	.164	.165½	3:5, 0.51 to red
52.908	.741	*b* 3	.167	.168	No companion
69.941	.776½	*b* 3	.164½	.166	1:4, 0.37 to vi.
76.107	.934	*a* 3	.173	.174	No companion
83.720	.548	*b* 1	.172	.173½	No companion
4404.927	.753	*b* 1	.174	.175½	Only 1:10 near
07.871	.716	*c* 4	.155	.158½	2:4, 0.06 to vi.; 2:4, 0.49 to red

TABLE I—*Continued*

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
4408.582	.420	*c* 4	.162	.165½	2:3, 0.22 to vi.; 2:3, 0.10 to red. Indeterminate
15.293	.127	*b* 1	.166	.167	2:8, 0.25 to vi.; 3:8, 0.43 to red. Probably neutral
22.741	.571	*b* 3	.170	.171	No companion
27.482	.314	*a* 3	.168	.169	2:5, 0.22 to vi.
30.785	.621½	*c* 4	.163½	.166½	1:3, 0.43 to vi.; 0:3, 0.14 to red. Neutral
42.510	.347	*c* 4	.163	.166	1:6, 0.49 to red. Neutral
43.365	.198	*b* 3	.167	.168	1:3, 0.37 to vi.; 5:3, 0.61 to red
47.892	.725	*c* 4	.167	.170	No companion
54.552	.386	*b* 3	.166	.167½	5:3, 0.40 to red
59.301	.126	*c* 4	.175	.178	2:3, 0.10 to vi.; 1:3, 0.22 to red. Indeterminate
61.818	.657	*a* 3	.161	.162	3:4, 0.35 to red; 1:4, 0.45 to vi.
66.727	.556	*b* 4	.171	.172	1:5, 0.37 to red
76.185	.024½	*b* 4	.160½	.162	3:4, 0.07 to red
89.911	.745	*a* 3	.166	.167	3:4, 0.34 to red
94.738	.572	*c* 4	.166	.169½	No companions
4528.798	.622½	*c* 4	.175½	.179	No companions
31.327	.155	*b* 3	.172	.174	2:5, 0.20 to vi.; 2:5, 0.47 to red
48.024	.853	*c* 4?	.171	.175	No companion
56.306	.131	*e*	.175	.171	3:4, 0.24 to vi.
92.840	.658	*c* 4?	.182	.186	2:4, 0.13 to vi.
4603.126	.947	*c* 4?	.179	.183	No companion
25.227	.059	*d*?	.168	.176	No companion
37.685	.519½	*d*?	.165½	.173½	4:5, 0.51 to red
47.617	.439	*c* 4?	.178	.182	Only very faint companion
68.331	.150	*d*?	.181	.189	2.4, 0.09 to vi.; 1:4, 0.42 to red
79.027	.856	*c* 4	.171	.175	2:6, 0.38 to red
91.602	.417	*c* 4	.185	.189	1:5 on each side. Probably neutral
4707.457	.288	*c* 5	.169	.167	2:5, 0.22 to red
27.582	.410	*d*?	.172	.180	2:3, 0.09 to red
27.676	.464	.....	.212	.....	Mn; 3:2, 0.09 to vi.
36.963	.786	*c* 5	.177	.184	2:6, 0.58 to red. Probably neutral
83.613	.433	*c* 5	.180	.187	No companion
87.003	.811	*c* 4	.192	.196	3:2, 0.28 to vi.
88.952	.762½	*c* 4	.189½	.193½	2:3, 0.58 to red
89.849	.657	*c* 4	.192	.196	2:3, 0.32 to vi.
4823.697	.524	*c* 5	.173	.180	3:5, 0.63 to red. Neutral
59.928	.758	*c* 5	.170	.178½	30:4, 1.6 to red. Too distant
71.512	.333	*c* 5	.179	.188	3:5, 0.52 to vi.; 1:5, 0.60 and 4:5, 0.82 to red
72.332	.153	*c* 5	.179	.187½	1:4, 0.22 to vi.
78.407	.225	*c* 5	.182	.190	3:4, 0.09 to vi.
90.948	.769	*c* 5	.179	.187	8:6, 0.74 to red. Too distant
91.683	.507	*c* 5	.176	.183	6:8, 0.74 to vi.; 1:8, 0.35 to red
4903.502	.325	*c* 5	.177	.184½	Only 0:5, 0.06 to vi.
19.174	.007	*c* 5	.167	.175	2:6, 0.63 to vi.
20.685	.518	*c* 5	.167	.174	No companion

TABLE I—*Continued*

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
4924.956	.776	*a*	.180	.182	No companion
38.997	.827½	*c*	.169½	.175	2:4, 0.42 to red; 2:4, 0.65 to vi.
39.868	.689	*a*	.179	.181	2:3, 0.45 to vi.
57.480	.310½	*c* 5	.169½	.176	8:5, 0.30 to red
57.785	.610	*c* 5	.175	.183	5:8, 0.30 to vi.
66.270	.104	*c* 5	.166	.174	No companion
78.785	.614½	*c*	.170½	.176	0:3, 0.05 to vi. Probably too faint
82.682	.526	*d*	.156	.166	2:4, 0.31 to red
85.432	.268	*c*	.164	.170	3:3, 0.30 to red
85.730	.562	*c*	.168	.176	3:3, 0.30 to vi.
94.316	.134	*a*	.182	.182½	No companion
5002.044	.881	*c*	.163	.171	No companion
05.896	.728½	*c*	.167½	.176	5:4, 0.41 to red
06.306	.134	*c*	.172	.180	4:5, 0.41 to vi.
12.252	.073	*a*	.179	.179½	1:4, 0.08 to red
15.123	.959½	*c*	.163½	.171½	3:3, 0.67 to vi. Too distant
22.414	.253	*c*	.161	.169	No companion
28.308	.132½	*a*	.175½	.177½	1:2, 0.37 to vi.
41.255	.078	*a*	.177	.179	3:4, 0.19 to vi.; 2:4, 0.54 to red
41.936	.762	*a*	.174	.176	2:4, 0.14 to vi.; 1:4, 0.43 to red
50.008	.827	*a*	.181	.183	No companion
51.825	.641	*a*	.184	.186	1:4, 0.14 to vi.; 0:4, 0.26 to red
65.207	.016	*e*	.191	.183	1:3, 0.06 to vi.; 2:3, 0.17 to red
68.944	.782	*c*	.162	.170	No companion
74.932	.747	*e*	.185	.181½	No companion
79.409	.228	*a*	.181	.183	3:4, 0.25 to vi.; 4:4, 0.51 to red
79.921	.742½	*a*	.178½	.180½	4:4, 0.51 to vi.; 1:4, 0.22 to red. Probably neutral
83.518	.344	*a*	.174	.175½	No companion
97.175	.992	*e*	.183	.179	0:3, 0.14 to vi. Too weak?
98.885	.706	*a*	.179	.181	1:3, 0.13 to vi; 0:3, 0.37 to red
5107.619	.454	*a*	.165	.167	4:4, 0.20 to red
07.823	.646	*a*	.177	.179	4:4, 0.20 to vi.
10.574	.415	*a*	.159	.161½	No companion. Double in sun?
23.899	.727½	*a*	.171½	.173½	No companion.
25.300	.137	*d*	.163	.176	1:3, 0.12 to red
27.533	.364	*a*	.169	.171	No companion
33.870	.672½	*e*	.197½	.187½	No companion
39.427	.269	*c*	.158	.167	4:4, 0.22 to red
39.644	.482	*c*	.162	.171	4:4, 0.22 to vi
51.020	.846	*a*	.174	.176	No companion
52.087	.917	*a*	.170	.172	0:3, 0.27 to red
62.449	.319	*d*	.130	.160	No companion
67.678	.492	*a*	.186	.187½	15:5, 0.18 to vi.
91.629	.473	*c*	.156	.165	No companion
92.523	.363	sub-*d*	.160	.171	2:5, 0.62 to red
95.113	.950	*a*	.163	.165	2:4, 0.53 to red
95.647	.472	*e*	.175	.171½	4:2, 0.53 to vi; 1:2, 0.58 to red
5202.516	.342	*a*	.174	.176	2:4, 0.08 to vi.
08.596	.429	.....	.167	.....	*Cr*; 2:5, 0.18 to red

TABLE I—*Continued*

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
5208.776	.611	sub-*d*	.165	.176	5:2, 0.18 to vi.
15.353	.197	sub-*d*	.156	.167	No companion
16.437	.279	*a*	.158	.160	No companion
17.552	.406½	*c*	.145½	.154½	No companion
27.043	.878	*c*	.165	.174	2:3, 0.34 to vi.; 5:3, 0.32 to red. Indeterminate
27.362	.190	*a* 4	.172	.174	3:5, 0.32 to vi.
30.030	.864	*c*	.166	.175	No companion
33.122	.957	sub-*d* 5	.165	.176	No companion
42.658	.496	*a*	.162	.164	No companion
63.486	.320	sub-*d*	.166	.176	No companion
66.738	.569	sub-*d* 5	.169	.180	No companion
69.723	.540	*a* 1	.183	.185	No companion. Double in sun?
70.558	.358	*a* 4	.200	.202	3:4, 0.12 to vi.
73.339	.178	sub-*d*	.161	.173	2:3, 0.22 to red
73.558	.380	sub-*d*	.178	.190	3:2, 0.22 to vi.
81.971	.804	sub-*d*	.167	.179	No companion
83.802	.634	sub-*d*	.168	.180	1:6, 0.48 to red. Neutral
5302.480	.315	sub-*d*	.165	.177	No companion
24.373	.196	sub-*d* 5	.177	.184½	No companion
28.236	.044	*a* 1	.192	.194	2:8, 0.28 and 2:8, 0.51 to red. Double in sun?
28.747	.538	*a* 4	.209	.210½	Doubtful. May be blend. Several to vi.
01.722	.538	.....	.184	.185½	Blend?
33.089	.907	*a* 4	.182	.184	1:4, 0.24 to vi.
40.121	.946	sub-*d* 5	.175	.186	No companion
41.213	.030	*a* 4	.183	.185	1:7, 0.12 to red. Relatively too weak
65.069	.862	*e*	.207	.196½	3:5, 0.53 to red
65.596	.404	*a*	.192	.194	5:3, 0.53 to vi.
67.669	.455	*e*	.214	.204	No companion
70.166	.960	*e*	.206	.202	1:6, 0.38 to vi.
71.734	.495	*a* 1	.239	.241	4:3, 0.08 to vi.
73.905	.704	*e*	.201	.194	No companion
83.578	.366	*e*	.212	.205	No companion
93.375	.184	*d*	.191	.201	No companion
97.344	.135	*a*	.209	.211	1:7, 0.48 to red
5404.357	.131	*e*	.226	.220	2:5, 0.33 to vi.
05.989	.780	*a*	.209	.211	1:6, 0.44 to vi.
11.124	.903	*e*	.221	.211	1:4, 0.30 to red
15.416	.189	*e*	.227	.217	No companion
24.290	.055	*e*	.235	.223	No companion
29.911	.701½	*a*	.209½	.211½	1:6, 0.19 to vi.; 0:6, 0.15 to red
34.740	.527	*a*	.213	.215	No companion
45.259	.041	*e*	.218	.209	No companion
47.130	.921	*a*	.209	.211	2:6, 0.33 to vi.
55.834	.614	*a*	.220	.222	2:4, 0.16 to vi.
63.174	.962	*e*	.212	.207	3:3, 0.32 to red
63.494	.272	*e*	.222	.218	3:3, 0.32 to vi.

TABLE I—*Continued*

λ_{Rowland}	$\lambda_{\text{I.A.}}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{\text{I.A.}}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{\text{I.A.}}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
5476.500	.296	*a*	.204	.206	3:1, 0.28 to red
76.778	.581½	*d*	.196½	.202½	1:3, 0.28 to vi.; 5:3, 0.34 to red
97.735	.522	*a*	.213	.215	No companion
5501.683	.470½	*a*	.212½	.215½	No companion
07.000	.784	*a*	.216	.218	No companion
35.644	.420	*a*	.224	.226	2:2, 0.58 to vi.; 0:2, 0.13 to red
43.414	.183½	*e*	.230½	.222½	No companion
55.122	.881	*e*	.241	.233	No companion
62.933	.712	*e*	.221	.213	No companion
63.824	.610	*d*	.214	.225	0:3, 0.09 to red
65.931	.701	*e*	.230	.222	No companion
69.848	.633	sub-*d*	.215	.224	No companion
73.075	.858	sub-*d*	.217	.227	1:6, 0.25 to red
76.320	.107	sub-*d*	.213	.223	No companion
86.991	.772	sub-*d*	.219	.231	No companion
94.884	.661	*e*	.223	.214	4:1, 0.19 to vi.
98.524	.300	*e*	.224	.215	4:1, 0.19 to red
5603.186	.963	sub-*d*	.223	.234	3:4, 0.10 to vi.
15.877	.661	sub-*d*	.216	.228	2:6, 0.36 to vi.
24.769	.561	sub-*d*	.208	.220	1:4, 0.52 to vi.
38.488	.278	sub-*d*	.210	.220	No companion
5659.052	.836	sub-*d*	.216	.227	1:4, 0.30 to vi.
5975.575	.352	*b*	.223	.226	Only air line, 1:3, near
77.007	.806	*d*	.201	.218	Only faint air lines near
83.908	.707½	*d*	.200½	.217½	No companion
85.040	.807	*e*	.233	.223	No companion
87.290	.059½	*e*	.230½	.220½	No companion
6003.239	.039	*d*	.200	.217	No companion
08.186	.967	*e*	.219	.209	6:4, 0.60 to red
08.785	.585	*d*	.200	.217	4:6, 0.60 to vi. Relatively weaker
20.401	.177	*b*?	.224	.228	2:4, 0.17 to vi.
24.281	.060½	*e*	.220½	.210½	No companion
27.274	.059	*b*	.215	.219	No companion
42.315	.008½	*e*	.226½	.216½	No companion
56.227	.992	*e*	.235	.225	No companion
65.709	.492	*b*	.217	.222	No companion
78.710	.481	*e*	.229	.219	2:5, 0.52 to red
6136.829	.624½	*b*	.204½	.210½	3:8, 0.38 to red
37.915	.701	*b*	.214	.219	No companion
48.040	.839	*d*	.201	.219	2:3, 0.09 to vi.
51.834	.631	*d*	.204	.222	No companion
57.945	.732	*b*	.213	.216	No companion
73.553	.344	*b*	.209	.213	No companion
80.420	.217½	*d*	.202½	.220½	No companion
91.779	.568	*b*	.211	.216	6:9, 0.39 to vi.
6200.527	.322	*b*	.205	.210	No companion
13.644	.439	*b*	.205	.210	No companion
19.494	.289	*b*	.205	.210	No companion
30.943	.734	*b*	.209	.213	No companion
32.856	.665½	*d*	.190½	.209½	No companion

TABLE I—*Continued*

$\lambda_{Rowland}$	$\lambda_{I.A.}$	Mount Wilson Group and Class	[Rowland − I.A.] $\Delta\lambda$ for $\lambda_{I.A.}$ at 1 Atm	[Rowland − I.A.] $\Delta\lambda'$ for $\lambda_{I.A.}$ at 0.5 Atm	Remarks: Ratio of Intensities (Companion : Line); Separation; Etc.
6246.535	.343	*d*	.192	.209½	No companion
52.773	.567½	*b*	.205½	.210½	No companion
54.456	.267	*b*	.189	.193	1:5, 0.07 to vi.
56.572	.373	*b*	.199	.205	No companion
65.348	.145	*b*	.203	.207	No companion
98.007	.802	*b*	.205	.210	2:5, 0.66 to red
6301.718	.523½	*d*	.194½	.210½	Only distant air line, 2:7
02.709	.513	*d*	.196	.215	Only air line, 2:5 on each side
18.239	.028	*b*	.211	.216	No companion
35.554	.341	*b*	.213	.218	No companion
37.048	.845	*d*	.203	.219	No companion
93.820	.612	*b*	.208	.212	No companion
6400.217	.021	*d*	.196	.211	2:8, 0.32 to red
08.233	.042	*d*	.191	.211	No companion
11.865	.673	*d*	.192	.207	No companion
21.570	.362	*b*	.208	.212	No companion
31.066	.859	*b*	.207	.211	No companion
6495.213	.993	*b*	.220	.224	Only faint air lines, 1:8

because they are the only lines for which the effect of pressure can be approximately eliminated before applying the test for the effect which is under investigation.

Column I of Table I contains the wave-lengths from Rowland's Preliminary Table of Solar Spectrum Wave-Lengths. Column 2 gives the laboratory wave-lengths of the same lines, at atmospheric pressure, on the International system. The method by which these were derived will be given in detail below. The values $\Delta\lambda$ give the differences (column 1 − column 2). Column $\Delta\lambda'$ gives the corresponding differences of wave-lengths after the International wave-lengths have been reduced to a pressure of 0.5 atmosphere. The reason and details for this reduction will be given later. In the last column are given such detailed remarks as will enable judgment, for each line separately, as to whether it comes within the possible or probable influence of other lines.

For column 2, the International secondary standards were adopted without modification. In order to include additional lines on the International system, but lines which are not standards, a comparison was made between the wave-lengths of Burns,[1] obtained

[1] *Lick Observatory Bulletin*, No. 247 (1913).

near sea-level, and those of St. John and Ware,[1] obtained in Pasadena and on Mount Wilson. For the purposes of this comparison the lines were separated according to their behavior under pressure, using the classification of Gale and Adams[2] with the addition by St. John and Ware,[3] and only those lines common to the two observers were taken for which the *group* according to behavior under pressure was known. The results of this comparison are summarized in Table II. The unit is 0.001 angstrom. The sub-

TABLE II

Group and Class		Mean λ	(Pasadena − Burns)		(Mount Wilson − Burns)	
e		4332 5406 6026 → 5450	− 2.7$_3$ −11.1$_{14}$ − 8.7$_7$ →	−9.4$_{24}$	+2.7$_3$ +0.6$_{14}$ +1.1$_7$ →	+1.0$_{24}$
a	*a* 1, 3, 4	4987	+ 1.5$_{11}$		+0.2$_8$	
	a	5033	− 0.7$_{13}$		−0.8$_{10}$	
	a	5174 → 5150	+ 1.1$_{13}$	+0.4$_{46}$	+2.8$_{11}$ →	+0.6$_{33}$
	a	5468	− 1.0$_9$		−1.2$_4$	
b	*b* 1	4287	− 0.7$_{10}$		−0.3$_7$	
	b 2	4272	− 0.5$_8$		+0.5$_8$	
	b 3	4365 → 4750	+ 0.2$_{10}$	−0.3$_{47}$	−0.3$_7$ →	−0.2$_{27}$
	b 4	4359	+ 0.7$_3$		+4.0$_2$	
	b	5236	− 0.4$_{22}$		−0.4$_{10}$	
c	*c* 2, 4	4556	− 0.7$_{18}$		−1.4$_{11}$	
	c	5061 → 4790	+ 0.4$_{15}$	−0.2$_{33}$	−0.8$_{14}$ →	−1.0$_{25}$
c 5		4840		−1.7$_{15}$		−2.6$_8$
sub-*d*		5400		+0.1$_{22}$		−0.5$_{12}$
d	*d* 5	4249	− 2.5$_4$		−2.0$_4$	
	d	5775 → 5530	+ 6.4$_{22}$ →	+5.0$_{26}$	−2.3$_{22}$ →	−2.2$_{26}$

scripts give the number of lines included in the means. The separation, in the individual groups, according to wave-length was made in order to see whether Gale and Adams' law of increase of pressure-displacement according to the cube of the wave-length (for Fe)

[1] *Astrophysical Journal*, **36**, 34, 1912; *ibid.*, **39**, 14, 1914; *Mt. Wilson Contr.*, Nos. 61 and 75.

[2] *Mt. Wilson Contr.*, No. 58; *Astrophysical Journal*, **35**, 15 and 31, 1912.

[3] *Mt. Wilson Contr.*, No. 61; *Astrophysical Journal*, **36**, 33, 1912.

applies to the differences under consideration here. The table does not show, with any degree of definiteness, such a relationship, and accordingly the results were combined into means irrespective of wave-length. Reference to this point will be made again farther on.

Evidently systematic differences exist between the wave-lengths of Burns and those of St. John and Ware. Burns (*op. cit.*, p. 28) had also made a comparison of his wave-lengths with the first list by St. John and Ware, and had drawn the following conclusions: "My measures are in good agreement with the values of St. John and Ware in the case of lines for which these observers find the same wave-length on Mount Wilson as in Pasadena. In cases where they find a difference between the mountain and sea-level, my measures are in excellent agreement with the wave-lengths found on the mountain, although my observations were made at sea-level." The progressive trend of the quantities in Table II, in both of the columns (Pasadena−Burns) and (Mount Wilson−Burns), seems to establish a fairly definite relationship between these systematic differences and pressure-shift. The relative shift between groups *e* and *d* is, for (Pasadena−Burns), 0.014 A, and, for (Mount Wilson−Burns), 0.003 A. This indicates, in regard to the effective pressures in the arcs, that Burns's arc was intermediate between the other two, and roughly about one-fifth of the way from that of Mount Wilson.

In order to account for this apparently anomalous result it seems necessary to take into account the internal pressure in the arc as well as the external (atmospheric) pressure. I quote from some recent work of Goos:

> My observations with different sorts of iron arcs now show that, with the same external pressure—atmospheric pressure—on plates from different parts of one and the same arc, further by change of current, arc length, etc., line-shifts occur which are of the same order of magnitude as those observed by St. John and Ware. I would like to offer as an hypothesis at this point that these shifts are due in part to pressure differences; that higher pressures prevail at the negative pole than in the middle of the arc and at the positive pole; and that with larger currents the pressure within the arc increases. This is because with larger currents more iron vaporizes, the vapor density becomes greater, and a pressure arises in the inner parts of the arc.[1]

[1] *Astrophysical Journal*, **38**, 141, 1913.

If the existence of such variations in the internal pressure of the arc be granted, then it follows also that even for the same observer moderate differences in the effective pressure for the separate spectrograms are possible, unless greater precautions are taken than have hitherto been considered necessary. As the entire region of spectrum under discussion here, and with the dispersion employed, requires not a single plate but a series of plates, moderate irregularities in the relative effective pressure differences between Burns and St. John and Ware might easily arise and thus disturb the smooth progression according to *group* in the differences (Pasadena −Burns) and (Mount Wilson−Burns), and in addition mask such effects as variation of pressure-shift as a function of the wave-length. In this fact, combined with the concentration in one or a few small regions of the spectrum, may also lie the real cause of the apparently marked separation of group sub-*d* from group *d* in Table II. In this connection it may be well to indicate another direction in which the accordance is incomplete. Table II gives for the relative displacement of group *e* to group *d* the ratio 3:2, while the measures of Gale and Adams give 2:3.

At present no criterion is available for adjusting the wave-lengths of Burns, Pasadena, and Mount Wilson to a standard effective pressure, and where the external pressure is 1 atmosphere. For the main purposes of this article no serious inaccuracy will be introduced by reducing the Pasadena and Mount Wilson wave-lengths to those of Burns as outlined in Table III, and in each case

TABLE III

CORRECTIONS APPLIED TO REDUCE TO BURNS

Group	Pasadena	Mount Wilson
a, *b*, *c*, and sub-*d*	.000	.000 A
e	+.009	−.001
d and *d* 5	−.005	+.002

combining with equal weights the mean of the values thus obtained for Pasadena and Mount Wilson with the wave-length obtained by Burns. As far as possible, lines of groups *e* and *d* will be employed only in an auxiliary way when used in combination with lines of groups *a*, *b*, and *c*.

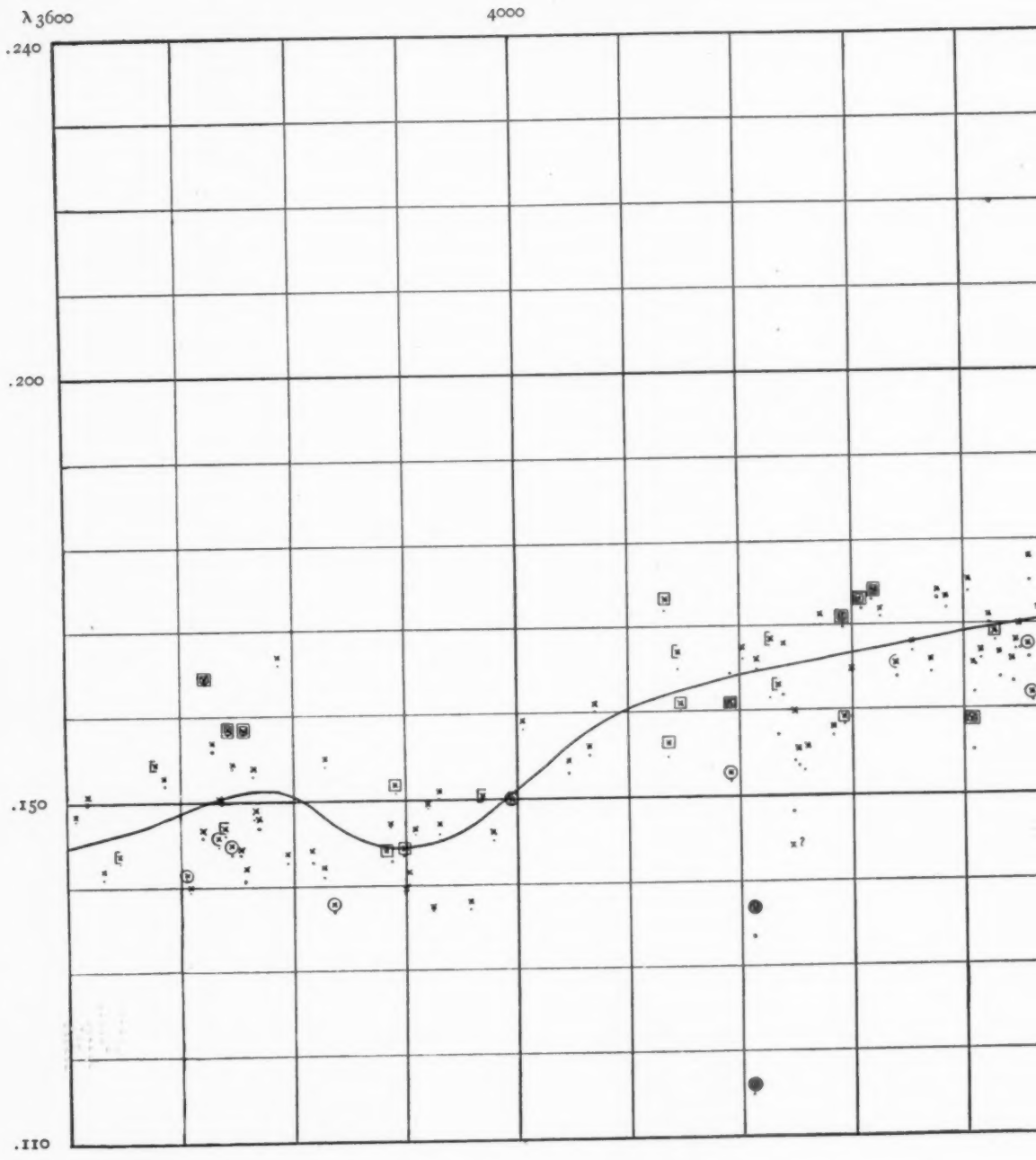
Column $\Delta\lambda'$ in Table I was obtained as follows: On the basis of a previous investigation on Rowland's wave-lengths (not yet published) it was found that the pressure in the solar reversing layer in which the Fe Fraunhofer spectrum originates is 0.5 atmosphere, relative to an assumed pressure of 1 atmosphere for the I.A. secondary standards. That this relative pressure of 0.5 atmosphere is essentially correct will be amply established later in this article. The laboratory wave-lengths $\lambda_{I.A.}$ correspond approximately to a pressure, external to the arc itself, of 1 atmosphere. The effective total pressure to which they correspond is at present unknown, and, besides, it is probably not strictly uniform over the entire length of spectrum covered. An effective pressure of 1 atmosphere is the best preliminary assumption that can be made for $\lambda_{I.A.}$. These wave-lengths were reduced to a pressure of 0.5 atmosphere to render them approximately homogeneous with Rowland's wave-lengths in the sun—except for the systematic differences between the two systems. This was done by applying to each line for which Gale and Adams had indicated the amount of displacement for given pressures a correction equal to $+\frac{1}{2}\Delta$ per atmosphere for lines of group *e*, and $-\frac{1}{2}\Delta$ per atmosphere for lines of groups *a*, *b*, *c*, and *d*, Δ being regarded as without sign of its own. In cases where the $\frac{1}{2}\Delta$ per atmosphere for the individual lines could not be obtained directly from the measures of Gale and Adams, these quantities were taken from Table IV. The values in this table were derived from

TABLE IV

CORRECTIONS $\frac{1}{2}\Delta$ PER ATMOSPHERE

Group	λ 4000	λ 4350	λ 4700	λ 5000	λ 5300	λ 5650	λ 6300
e	+.003	+.004	+.005	+.006	+.007	+.009	+.010
a	−.001	−.001	−.002	−.002	−.002	−.003	−.003
b	−.001	−.001	−.002	−.002	−.002	−.003	−.004
c	−.002	−.003	−.004	−.005	−.006	−.007	−.009
c 5	.....	.....	−.007	−.008	.....	.....	.....
d and sub-*d*	−.005	−.007	−.008	−.010	−.012	−.015	−.017

the lines of known displacement, in part by actual means and for separate regions of the spectrum, and in part by the application, to the means, of the law of variation with the cube of the wave-length which was found for the iron spectrum by Gale and Adams.


λ 3600
4000
.240
.200
.150
.110

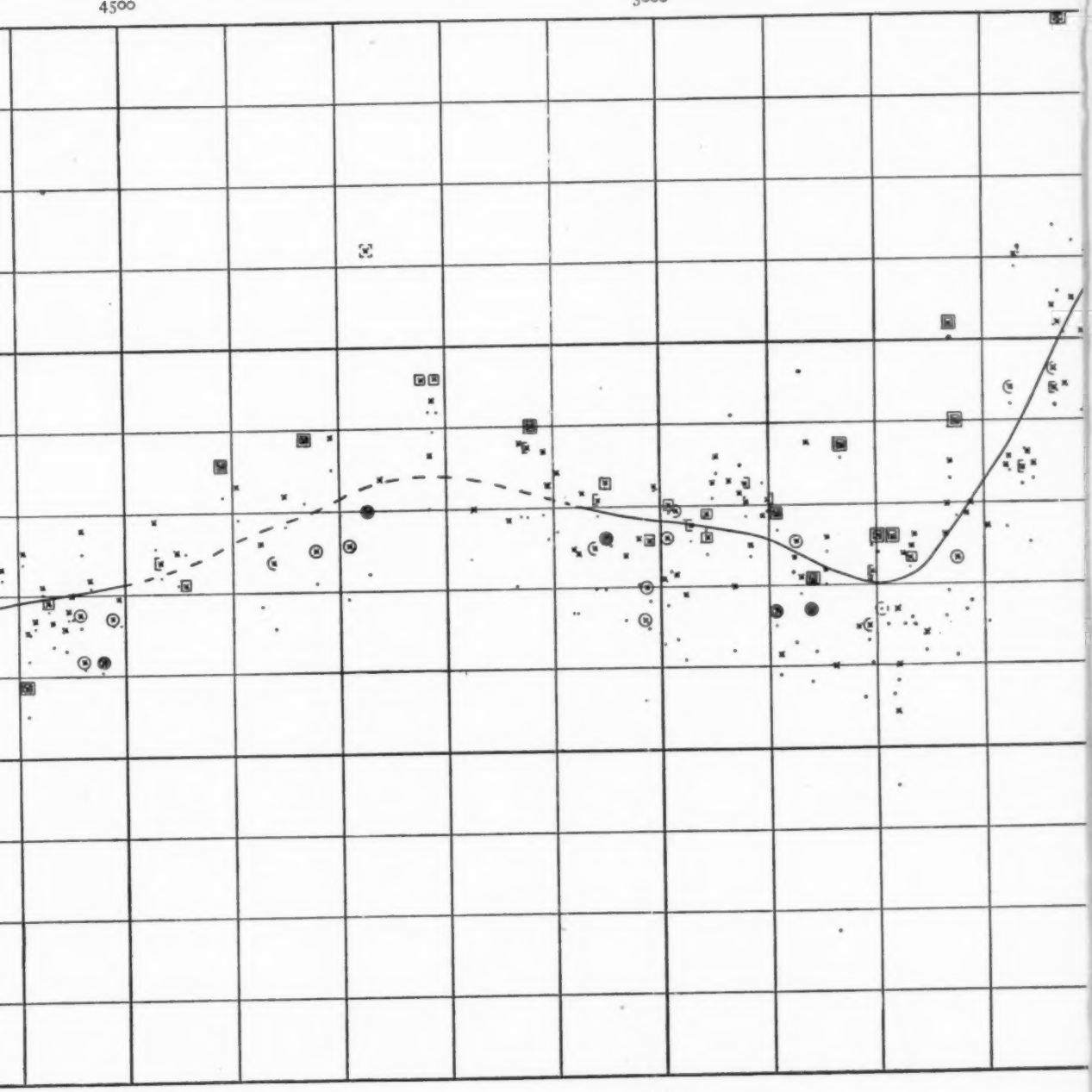


FIG. 1

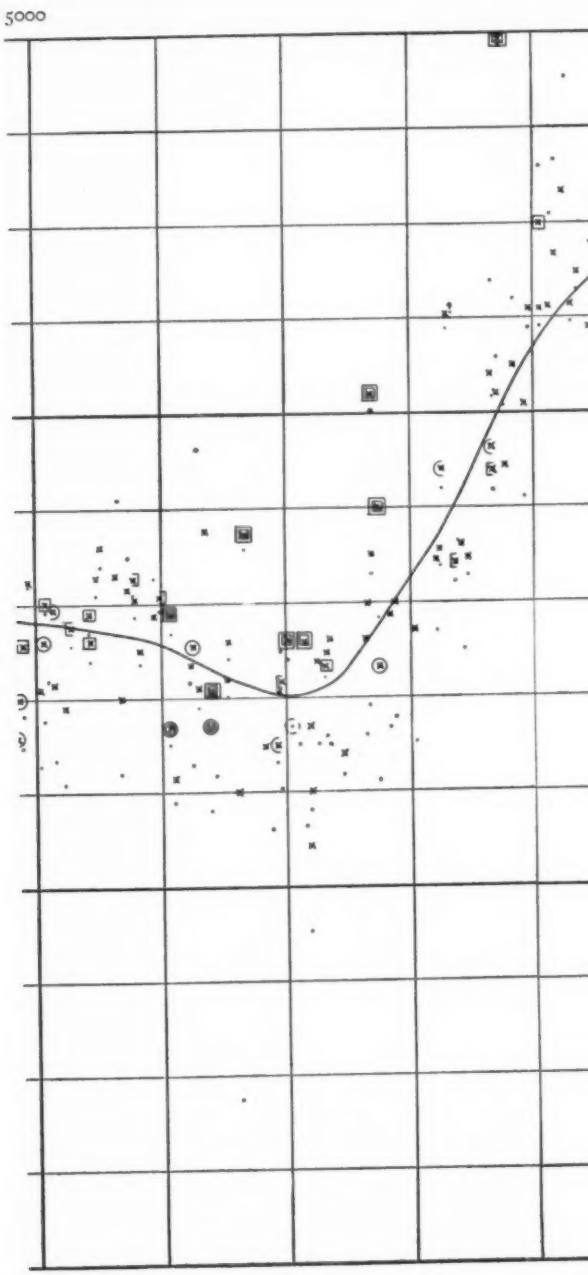
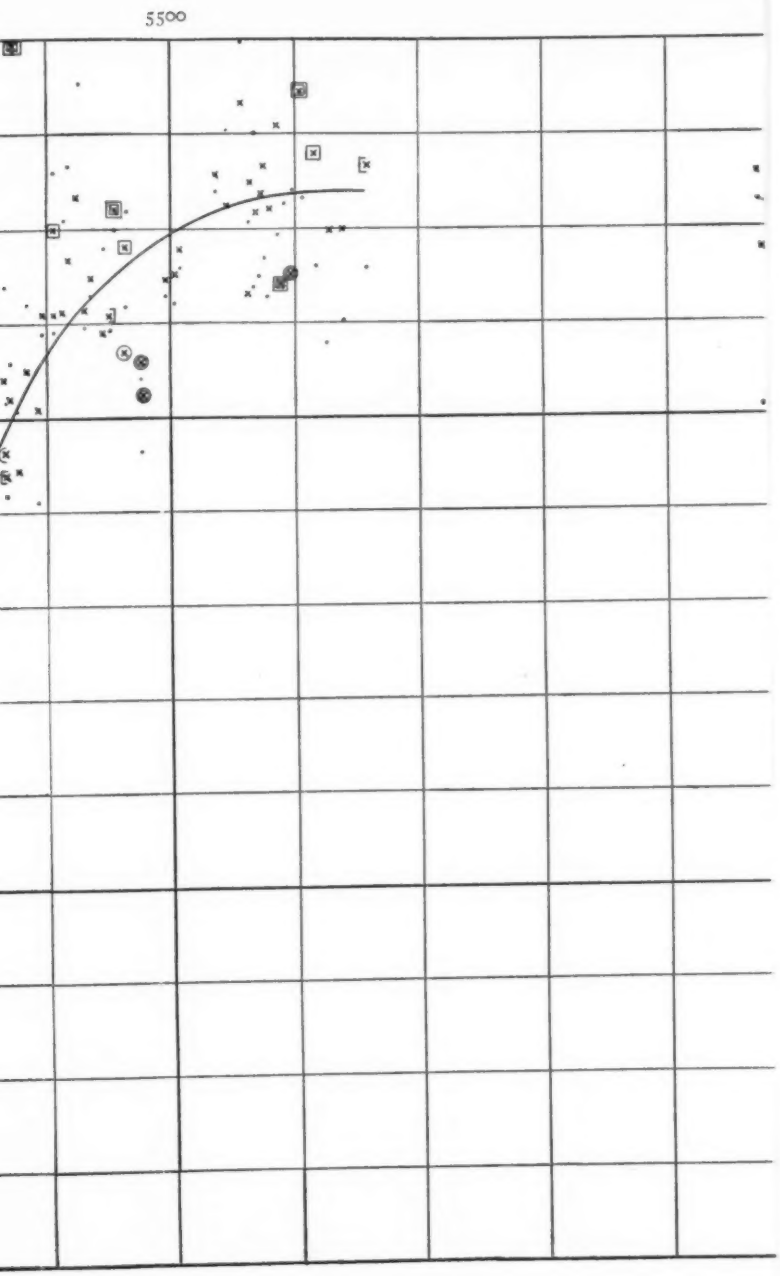
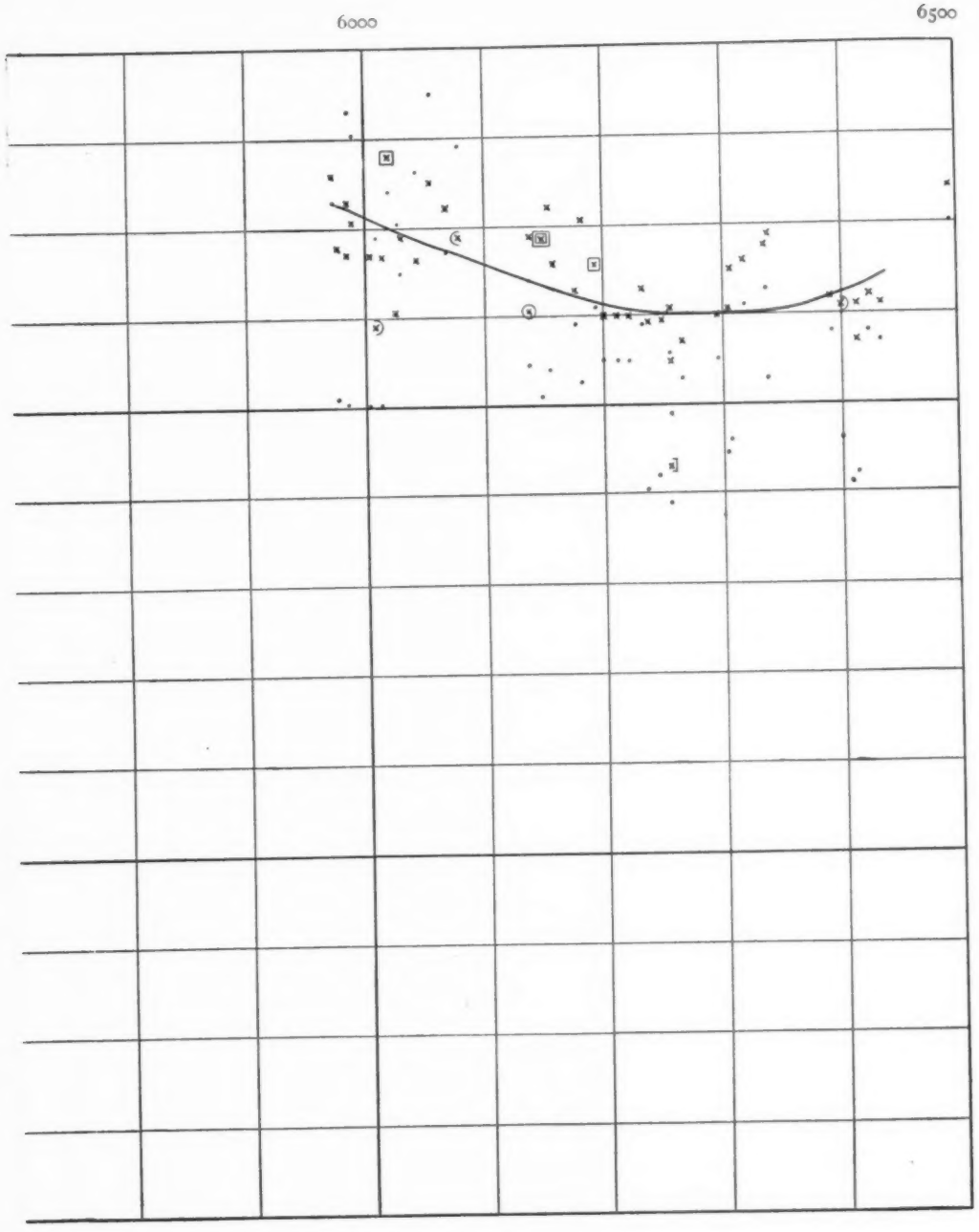


FIG. 1


5500


6000
6500

DERIVATION AND DISCUSSION OF RESULTS

The choice, from Table I, of the lines which should contain a Julius effect—if there is really such an effect—was made a separate piece of work in which no reference was made to columns $\Delta\lambda$ and $\Delta\lambda'$. In fact these two columns had been formed on a separate sheet, and thus one could not thereby be subconsciously influenced in the decision for or against the probability of a Julius effect. The lines selected are given in Tables V and VI, separated according as the companion line is toward the red or toward the violet in the solar spectrum. The actual basis on which this selection was made can readily be seen from the detailed remarks for each line in Table I. The companion lines need not necessarily be *stronger* lines, but must only be of *sufficient* strength and proximity. The essential requirement in making such selections is that the adopted principle of selection be reasonably definite, and that it be adhered to as rigidly as the conditions allow. At the conclusion of the investigat on the writer re-examined, in Rowland's tables, the lines listed in Table I in order to learn to what extent a choice made at that time would differ from the lists given in Tables V and VI. It was found that with the possible exception of two or three lines the identical selection would have been made.

The weights for the individual lines were assigned entirely on the basis of the intensities, the relative intensities, and the separation from the companion lines. For only two of the lines retained, λ 6008 and λ 4227, does the separation appreciably exceed 0.5 A. For the former it is 0.6 A, and the intensity of the companion line is 50 per cent stronger than that of the line; for the latter the separation and relative intensity of the companion line are respectively 0.7 A and 500 per cent. All lines with separation close to or greater than 0.5 A were placed in the class of smallest weight.

The systematic differences between the Rowland and the International systems,[1] for the iron spectrum, are obtained from a graph with wave-lengths as abscissae and the values $\Delta\lambda'$ as ordinates. Fig. 1 is a reproduction of this graph. The quantities $\Delta\lambda'$ are

[1] As the greater part of the material forming the basis for this article is taken from an investigation on the Rowland system, which has not yet been published, a more complete discussion of the systematic differences between the Rowland and the International systems is reserved for another article.

TABLE V

FE LINES WITH COMPANIONS TOWARD THE RED IN THE SOLAR SPECTRUM

λ Rowland	Ratio of Intensities (Comp. : Line)	Separation	Weight	To Reduce Point to Curve	Group	Remarks
		A		A		
3705.708..	2: 9	0.14	1	+.007	*a* 1	
3735.014..	4:40	0.47	½	+.004	*b* 1	Doubtful?
3743.508..	2: 6	0.12	1	+.006	*b* 1	
3834.364..	4:10	0.14	1	+.009	*b* 1	And 3:10, 0.36 to vi.
3997.547..	2: 4	0.09	1	+.001	*b* 4	And 1:4, 0.29 to vi.
4101.595..	3: 6	0.25	1	+.011	*a* or *b*	
4204.101..	4: 3	0.06	2	+.048	*b* 3	And 2:3, 0.37 to vi.
4210.494..	3: 4	0.07	3	+.027	*c* 5	
4337.216..	3: 5	0.51	½	+.002	*b* 3	
4454.552..	5: 3	0.40	1	+.003	*b* 3	
4461.818..	3: 4	0.36	1	+.008	*a* 3	And 1:4, 0.45 to vi.
4476.185..	3: 4	0.07	3	+.008	*b* 4	
4489.911..	3: 4	0.34	1	+.004	*a* 3	
4637.685..	4: 5	0.51	½	+.004	*d*?	
4679.027..	2: 6	0.38	1	+.005	*c* 4	
4707.457..	2: 5	0.22	1	+.006	*c* 5	
4727.582..	2: 3	0.09	2	+.003	*d*?	
4938.997..	2: 4	0.42	½	+.005	*c*	And 2:4, 0.65 to vi.
4957.480..	8: 5	0.30	2	+.003	*c* 5	
4982.682..	2: 4	0.31	1	+.013	*d*	
4985.432..	3: 3	0.30	1	+.009	*c*	
5005.896..	5: 4	0.41	1	+.002	*c*	
5012.252..	1: 4	0.08	½	−.002	*a*	
5107.619..	4: 4	0.20	2	+.008	*a*	
5125.300..	1: 3	0.12	1	−.002	*d*	
5139.427..	4: 4	0.22	2	+.006	*c*	
5195.113..	2: 4	0.53	½	+.006	*a*	
5208.596..	2: 5	0.18	0	+.003	.....	Cr line; weight 0—"group" is unknown
5273.339..	2: 3	0.22	1	+.004	sub-*d*	
5328.236..	2: 8	0.28	½	−.007	*a* 1	Double in sun?
5365.069..	3: 5	0.53	½	.000	*e*	
5463.174..	3: 3	0.32	1	+.009	*e*	And 1:3, 0.47 to vi.
5476.500..	3: 1	0.28	2	+.011	*a*	
5476.778..	5: 3	0.34	2	+.015	*d*	And 1:3, 0.28 to vi.
5598.524..	4: 1	0.19	3	+.008	*e*	
6008.186..	6: 4	0.60	½	+.012	*e*	
6078.710..	2: 5	0.52	½	−.002	*e*	
6136.829..	3: 8	0.38	1	+.004	*b*	
6400.217..	2: 8	0.32	½	+.001	*d*	
Weighted mean				+.0094		
Sum of weights				45.5		
Straight mean				(+.005)		
Number of lines				38		

TABLE VI

FE LINES WITH COMPANIONS TOWARD THE VIOLET IN THE SOLAR SPECTRUM

λ Rowland	Ratio of Intensities (Comp. : Line)	Separation	Weight	To Reduce Point to Curve	Group	Remarks
		A		A		
3647.988..	4:12	0.43	½	+.002	*b* 1	
3680.069..	2: 9	0.25	½	−.007	*a* 1	And 2:9, 0.46 to red
3722.729..	3: 6	0.09	2	−.014	*a* 1	
3737.281..	5:30	0.22	½	+.003	*a* 1	
3746.058..	8: 6	0.34	2	−.008	*a* 1	
3748.650..	10: 1	0.24	3	−.008	*b* 1	And 1:1, 0.17 to red
3887.196..	3: 7	0.25	1	.000	*b* 1	
3888.671..	2: 5	0.11	1	−.008	*b* 1	And 2:5, 0.30 to red
3895.803..	3: 7	0.22	1	.000	*a* 1	
3969.413..	6:10	0.53	½	−.004	*b* 1	
4132.235..	2:10	0.14	1	−.012	*b* 1	And 3:10, 0.46 to red
4134.840..	3: 5	0.25	1	+.006	*b* 4	
4144.038..	4:15	0.47	½	−.005	*b* 1	
4147.836..	2: 4	0.33	1	+.002	*a* or *b*	
4191.843..	6: 3	0.25	2	+.003	*e*	
4227.606..	20: 4	0.70	½	−.004	*d* 5	And 1:4, 0.13 on same side
4233.772..	4: 6	0.44	½	+.002	*d* 5	
4291.630..	2: 2	0.35	1	+.007	*a*	And 1:2, 0.26 on same side
4294.301..	2: 5	0.10	2	−.005	*b* 2	
4308.081..	3: 6	0.17	2	−.006	*b* 1	And fainter line on each side
4315.262..	3: 4	0.12	2	−.007	*b* 3	
4407.871..	2: 4	0.06	2	+.011	*c* 4	
4427.482..	2: 5	0.22	1	.000	*a* 3	
4531.327..	2: 5	0.20	½	−.002	*b* 3	And 2:5, 0.47 to red
4556.306..	3: 4	0.24	1	+.002	*e*	
4592.840..	2: 4	0.13	2	−.010	*c* 4?	
4668.331..	2: 4	0.09	2	−.010	*d*?	
4727.676..	3: 2	0.09	0	−.029	.....	Mn, weight 0—"group" unknown
4787.003..	3: 2	0.28	1	−.012	*c* 4	
4789.849..	2: 3	0.32	1	−.012	*c* 4	
4872.332..	1: 4	0.22	½	−.006	*c* 5	
4878.407..	3: 4	0.09	2	−.008	*c* 5	
4939.868..	2: 3	0.45	½	−.002	*a*	
4957.785..	5: 8	0.30	1	−.004	*c* 5	
4985.730..	3: 3	0.30	1	+.003	*c*	
5006.306..	4: 5	0.41	1	−.002	*c*	
5028.308..	1: 2	0.37	½	.000	*a*	
5041.255..	3: 4	0.19	1	−.002	*a*	And 2:4, 0.54 to red
5041.936..	2: 4	0.14	1	+.001	*a*	And 1:4, 0.43 to red
5079.409..	3: 4	0.25	½	−.006	*a*	And 4:4, 0.51 to red
5098.885..	1: 3	0.13	½	−.005	*a*	And 0:3, 0.37 to red
5107.823..	4: 4	0.20	2	−.004	*a*	
5139.644..	4: 4	0.22	2	+.002	*c*	
5167.678..	15: 5	0.18	3	−.016	*a*	
5195.047..	4: 2	0.53	½	−.001	*e*	And 1:2, 0.58 to red
5202.516..	2: 4	0.08	2	−.006	*a*	
5208.776..	5: 2	0.18	3	−.006	sub-*d*	

TABLE VI—*Continued*

λ Rowland	Ratio of Intensities (Comp. : Line)	Separation	Weight	To Reduce Point to Curve	Group	Remarks
		A		A		
5227.362..	3: 5	0.32	1	−.003	*a* 4	
5270.558..	3: 4	0.12	2	−.026	*a* 4	
5273.558..	3: 2	0.22	2	−.014	sub-*d*	
5333.089..	1: 4	0.24	½	+.005	*a* 4	
5365.596..	5: 3	0.53	½	+.003	*a*	
5371.734..	4: 3	0.08	3	−.042	*a* 1	
5404.357..	2: 5	0.33	1	−.012	*e*	
5447.130..	2: 6	0.33	½	+.003	*a*	Double in sun?
5455.834..	2: 4	0.16	2	−.007	*a*	
5463.494..	3: 3	0.32	1	−.002	*e*	
5594.884..	4: 1	0.19	2	+.009	*e*	Measured only by Burns with large probable error
5603.186..	3: 4	0.10	2	−.011	sub-*d*	
5615.877..	2: 6	0.36	1	−.004	sub-*d*	
5659.052..	1: 4	0.30	½	−.003	sub-*d*	
6020.401..	2: 4	0.17	1	−.008	*b*?	
6148.040..	2: 3	0.09	2	−.005	*d*	
6191.779..	6: 9	0.39	1	−.004	*b*	
6254.456..	1: 5	0.07	½	+.017	*b*	Doubtful
Weighted mean				−.0066		
Sum of weights				81.5		
Straight mean				(−.0041)		
Number of lines				64		

plotted as crosses. For purposes which will become evident later, the values $\Delta\lambda$ are also plotted, being represented in the graph by dots. Of the crosses, those representing lines which have companions toward the red in the solar spectrum (Table V) are provided with a semicircle, a circle, or two concentric circles, according as the adopted weight is ½, 1, or 2 and greater, respectively. Similarly, lines with companions toward the violet in the solar spectrum (Table VI) are accompanied by half a square, an entire square, or two squares.

The curve in Fig. 1 (for the quantities $\Delta\lambda'$) represents the systematic difference, as adopted for this investigation, between the Rowland and the International systems. It was originally drawn to represent best the normal places formed from the lines of groups *a* and *b* alone, because these lines, being only slightly affected by pressure, may be regarded as practically independent of a moderate

uncertainty in the adopted pressure difference of 0.5 atmosphere between the two systems of wave-lengths. However, a later close inspection of the points showed that no material change in the position of the curve results when the lines of groups *c*, *d*, and *e* are also included.

To anticipate somewhat, two facts stand out quite prominently in the graph. First, the correction of the wave-lengths in the International system to a pressure of 0.5 atmosphere has brought in toward the curve the lines which are strongly affected by pressure—namely, those of groups *c*, *d*, and *e*. Without the application of these corrections, the lines of groups *c* and *d* are decidedly below the curve, and those of group *e* are above the curve. This "drawing in" of the points toward the curve is gratifying, as it shows that the reduction of the wave-lengths in the International system to a pressure of 0.5 atmosphere has made them practically homogeneous with Rowland's wave-lengths in the sun—except, of course, for the systematic differences between the two systems as represented by the curve. Secondly, the separation, to the two sides of the curve respectively, of the circles and squares is quite pronounced. It is also evident that this separation of the circles and squares from each other is not dependent upon any particular position of the curve.

Column 5 in Tables V and VI gives the corrections which must be applied to reduce the points $\Delta\lambda'$ to the curve. This column furnishes the evidence required for our problem.

Column 5 in Table V contains only four negative values and one zero in a total of 38 lines. This strong preponderance of positive quantities shows that lines which have companions toward the red in the solar spectrum are systematically shifted toward the violet. The weighted mean, +0.0094 A, may be somewhat too high. If we were to omit the abnormally large value of +0.048, and reduce to weight 1 the relatively large value of +0.027, we should obtain for the weighted mean the value +0.0069. It seems that 0.007 A may be a fair approximation to the true displacement toward the violet, at λ 5000, for a mean ratio of intensities of 3:4,[1] and a mean separation of 0.24 A.

[1] These are not actual means of intensities but merely relative values of the intensities of companion line and line.

Table VI shows with nearly equal certainty that solar lines having companions on their violet sides are shifted toward the red. The weighted mean is −0.0066 A. One value, −0.042, seems abnormally large. If this be omitted, the weighted mean reduces to −0.0052 A. Possibly 0.005 A may be not far from the true displacement toward the red, at λ 5000, for a mean ratio of intensities of 8:9,[1] and a mean separation of 0.21 A.

We note that the displacement is greater in amount when the companion is toward the red than when it is toward the violet. It will be recalled that this is one of the requirements of the anomalous-dispersion theory, and I judge that the relative values of the displacements in the two cases are about what would be expected. The displacements being appreciably smaller for companion toward the violet would also account for the fact that in this case 26 per cent of the lines give values of opposite sign from the mean, while for companion toward the red only 11 per cent have opposite sign.

The weights which were assigned to the individual lines may be regarded as in part a measure of the certainty with which the Julius effect should be shown according to separation and ratio of intensities, and in part as a very rough indication of the magnitude of the effect. Naturally we should expect the displacement to be greater when the separation is small than when it is large. So also the certainty of such an effect (if it exists at all) is greater when the companion line is relatively the stronger. At the same time it is quite evident from Tables V and VI that the effect shown is not dependent upon the adopted system of weighting.

When the lines are grouped according to the separation from their companions and the direct means taken, we obtain the results given in Table VII. The subscripts indicate the number of lines

TABLE VII

MEANS—DISPLACEMENT ACCORDING TO SEPARATION FROM COMPANION

LINES WITH	SEPARATION		
	0.0 to 0.2 A	0.2 to 0.4	0.4 and Greater
Companion toward the red	$+.010_{31}$	$+.006_{517}$	$+.003_{610}$
Companion toward the violet	$-.007_{324}$	$-.002_{431}$	$-.001_{09}$

included in each mean. The decreasing displacement with increasing separation is quite definitely shown and justifies, a posteriori, the increased weight with diminished separation. For the lines with companions toward the red the mean separations are respectively 0.11, 0.30, and 0.49 A, and for the lines with companions toward the violet, 0.12, 0.28, and 0.50 A. If the values in Table VII are plotted as ordinates, with the mean separations as abscissae, we obtain curves *a* and *b* in Fig. 2. These curves represent first approximations of the relations between the amount of displacement and the separation of the line from its companion. Curve *a* gives the amount of displacement toward the violet, for separations

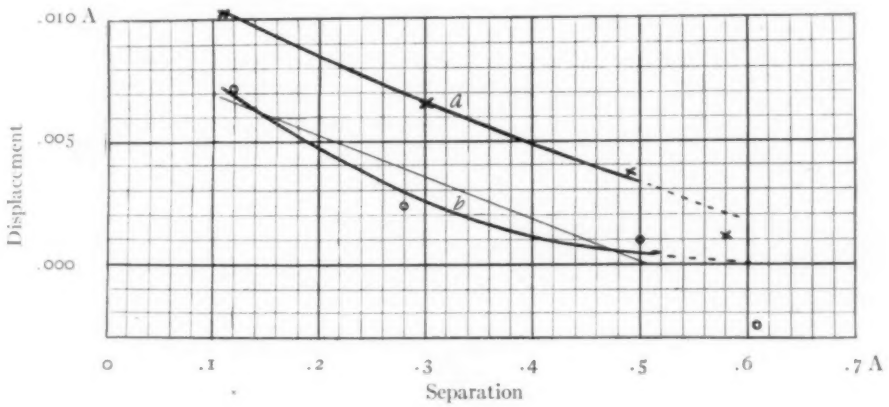


FIG. 2.—Displacements according to separation from companion

between 0.1 and 0.5 A, for lines which have companions toward the red. Curve *b* gives, for lines with companions toward the violet, the amount of displacement toward the red, between the same limits of separation. An extrapolation of the curve toward the right indicates that we may expect the effect of companion lines to be inappreciable at separations of 0.7 A and greater. With a view to determining roughly these extrapolated portions of the curves, Table I and Rowland's table were gone over again and additional lines were selected with separations between 0.5 and 0.7 A. The values thus obtained are plotted in Fig. 2 at 0.58 and 0.61 A. These must be regarded as quite uncertain, but if

given any weight at all, they would indicate that the Julius effect becomes inappreciable at a somewhat smaller limit than 0.7 A, especially for lines with companions toward the violet. It seems not improbable that for large separations both the intensity and the relative intensity of the companion line become relatively more important factors. In the near future we may expect a sufficient amount of additional material to become available to warrant making a closer approximation of the quantitative relation between displacement on the one hand and separation and intensities on the other.

As in Tables V and VI, so also in Table VII, the displacements are smaller in amount (disregarding signs) when the companion line is toward the violet than when it is toward the red. In Table VII this is seen to be true within each of the limits of separation.

In Table VIII are given the displacements, taken from column 5 of Tables V and VI, separated according to pressure groups. This table gives, both in the division for lines with companions toward the red and in that with companions toward the violet, a mean displacement which is practically the same for all groups. This shows that, first, the preliminary value of 0.5 atmosphere which was found for the pressure in the reversing layer of the sun where the Fe lines originate, and, secondly, the pressure displacements per atmosphere (in the mean) which were found by Gale and Adams, are close approximations to the correct values. It was the writer's original intention to make a second approximation of the pressure in the solar reversing layer at the conclusion of this investigation, but in view of the good agreement found above, this seems unnecessary at the present time, especially as additional material may be expected to become available in the near future.

The evidence adduced above is quite definite as to the observed facts. These are: Fraunhofer's lines, as given in Rowland's tables, are displaced when they have close companions; the displacement is (*a*) toward the violet when the companion line is toward the red, and (*b*) toward the red when the companion is toward the violet. The displacement in (*a*) is greater than in (*b*), and in both it increases as the separation between the lines diminishes. This effect appears to be due to anomalous dispersion, and conforms very

closely with the theoretical requirements as developed by Julius. One other possible cause that suggested itself to the writer is personality in the measurement of close pairs of lines. From the writer's own experience in measurement this did not seem probable. In order to gather further evidence along this line from other observers, St. John and Ware's[1] table of close pairs of lines was

TABLE VIII

FROM TABLES V AND VI, SEPARATED ACCORDING TO *Group* (IN UNITS OF 0.001 A)

	WITH COMPANIONS TOWARD THE RED					WITH COMPANIONS TOWARD THE VIOLET				
	a	*b*	*c*	*d*	*e*	*a*	*b*	*c*	*d*	*e*
	+ 7	+ 4	+ 5	+ 4	0	− 7	+ 2	+11	− 4	+ 3
	+ 8	+ 6	+ 5	+ 3	+ 9	−14	− 8	−10	+ 2	+ 2
	+ 4	+ 9	+ 9	+13	+ 8	+ 3	0	−12	−10	− 1
	− 2	+ 1	+ 2	− 2	+12	− 8	− 8	−12	− 5	−12
	+ 8	+11	+ 6	+15	− 2	0	− 4	+ 3	− 6	− 2
	+ 6	+48	+27	+ 1		+ 7	−12	− 2	−14	+ 9
	− 7	+ 2	+ 6	+ 4		0	+ 6	+ 2	−11	
	+11	+ 3	+ 3			− 2	− 5	− 6	− 4	
		+ 8				0	− 5	− 8	− 3	
		+ 4				− 2	− 6	− 4		
						+ 1	− 7			
						− 6	− 2			
						− 5	− 8			
						− 4	− 4			
						−16	+17			
						− 6				
						− 3				
						−26				
						+ 5				
						+ 3				
						−42				
						+ 3				
						− 7				
						+ 2				
Means....	+4.4	+8.6	+7.9	+5.4	+5.4	−5.2	−2.9	−3.8	−6.6	−0.2
No. of lines	8	10	8	7	5	24	15	10	9	6

taken and corresponding columns added for Burns. An inspection of this table does not disclose any pronounced personal differences between the four observers in the measured differences of wavelength between the components of the pairs. Although, taken by itself, this does not entirely remove personality in Rowland's measures as a possible cause, it nevertheless places the chances

[1] *Astrophysical Journal*, **39**, 23, 1914.

against this as the cause. However, the principal objection is that it would be especially difficult to explain, on this ground, the observed inequality of the displacements for the two components.

It will be recalled that the investigation by Julius and St. John (*op. cit.*) on St. John's measures of the Evershed effect led to opposite conclusions as to the presence in those measures of an effect due to anomalous dispersion. Julius found that such an effect was superimposed upon the Evershed effect. By a different choice of lines and a somewhat different treatment of the data St. John found that the Julius effect vanishes. It was thought of interest to apply to the lines which were chosen by Julius and added by St. John (without referring to St. John's complete original list) the conditions of selection which were used in the present investigation. When this was done and those lines were eliminated which are indeterminate, the results summarized in Table IX were obtained. St.

TABLE IX

CHANGE IN THE EVERSHED EFFECT

Companion to Red				Companion to Violet			
38 original,	Σ weight	47	−.0026	34 original,	Σ weight	44	+.0012 A
19 additional	"	19	+.0019	17 additional	"	20	−.0011
Weighted mean,	"	66	−.0013	Weighted mean,	"	64	+.0005

John's residuals were used for this purpose. The final weighted means for companion to red and companion to violet are in the direction required by the Julius effect, though the numerical values are so small that they cannot—taken by themselves—be accepted as a definite indication of the effect.

SUMMARY AND CONCLUSIONS

According to the theory of anomalous dispersion as developed by Julius, Fraunhofer lines which are separated from each other by only very short distances (about 0.5 A or less) should produce mutual displacements of the lines, the violet and red components of a pair being displaced in opposite directions, the former somewhat more than the latter. Rowland's Preliminary Table of Solar Spec-

trum Wave-Lengths forms a suitable basis with which to make a test for this effect. In the test made (which is necessarily preliminary, the Fe lines alone were employed, the chief reasons for thus restricting the data being the following: (*a*) For these lines well-determined laboratory wave-lengths are available for the necessary comparisons. (*b*) As spectrum lines are affected selectively by pressure and as it is desirable to eliminate the unequal pressure effects, the data were further restricted to those Fe lines which had been classified according to pressure-shifts.

The principal results derived are: Lines with close companions toward the red in the solar spectrum are shifted toward the violet, and lines with close companions toward the violet are shifted toward the red. The displacement varies in amount with the separation of the lines, though for all separations it is greater when the companion line is toward the red than when it is toward the violet of the line. For a mean separation of 0.22 A the displacements are respectively 0.007 A and 0.005 A. These facts are in accord with the requirements of Julius' theory, and they seem definitely to establish the operation of anomalous dispersion in the sun.

Additional results and conclusions are: (1) A method is developed by which Rowland's Preliminary Table of Solar Spectrum Wave-Lengths is made available for comparison of solar wave-lengths with the best recent laboratory wave-lengths. As was also shown by Gale and Adams, Rowland's tables of wave-lengths are still too valuable to be discarded. By the development of a method of connecting laboratory wave-lengths with solar wave-lengths, both are made available for the study of various solar and stellar problems. (2) The Mount Wilson classification of spectrum lines according to behavior under pressure is confirmed. (3) It was shown that the pressure in the solar reversing layer where the Fe Fraunhofer lines originate is 0.5 atmosphere. (4) As a direct consequence of the progressive variation in intensity of lines in stellar spectra—some lines gradually disappearing and new lines coming in and increasing in strength as we proceed from type to type, thereby causing neighboring lines to change very markedly in relatively intensity, some lines gradually losing companions while others gain them—anomalous dispersion becomes *one* of the causes

producing the changes of wave-length which are progressive with the stellar spectral type.

This investigation shows (as was shown before) that the detailed study of spectrum lines according to their behavior under pressure marks a distinct step in stellar spectroscopy. When eventually standard wave-lengths are referred to a standard pressure, a long step will have been taken toward facilitating the problem of determining the pressure in stellar atmospheres, especially in the stellar spectral types A to M. This seems clearly foreshadowed owing to the differential separation—from a mean curve—of the lines of the different pressure groups when the pressure is varied. The process of determining the pressures will be similar to the processes that were employed in determining (*a*) the pressure in the solar reversing layer relative to that of the International secondary standards, and (*b*) the relative pressures in the arcs of Burns and of Mount Wilson and Pasadena.

DUDLEY OBSERVATORY
ALBANY, N.Y.
March 30, 1915

THE STARK EFFECT AND ATOMIC STRUCTURE

A CRITIQUE OF CERTAIN RECENT WORK

By GORDON S. FULCHER

In the autumn of 1913 Stark discovered that when certain spectrum lines are emitted in a strong electric field they are very markedly affected. A *low-dispersion spectroscope* shows Hα resolved into three polarized components, Hβ into four, Hγ into five, etc. The diffuse series of helium and lithium are also similarly analyzed. The relative position and intensity of the components as observed in a rough analysis are approximately indicated in Fig. 1. The *p*-components are polarized parallel to the field; the *s*-components at right angles to the field. Investigation made later by Stark with a very remarkable spectrograph combining considerable dispersion with great light-gathering power showed that the components just noted are all complex. The total number of components observed in this *fine analysis* varied from 18 to 28 for different H lines. The details will be presented later.

Since these spectrum lines are usually emitted in an electric field, it seems strange that the Stark effect has escaped detection for so long. In fact Lo Surdo did observe it immediately in front of the cathode in a capillary discharge tube, and the Lo Surdo arrangement is the most convenient for qualitative observations. But Stark's technical knowledge of canal-ray phenomena was necessary to overcome the experimental difficulty of securing the intense emission of light in a constant field of about 50,000 volts per cm, so that the effect could be studied quantitatively. To him and to his co-workers we owe most of our knowledge of the effect of an electric field on the frequencies of light emitted in it, and to him rightly belongs the honor of the association of the phenomenon with his name.

The extraordinary number of data accumulated during the eight months immediately following the discovery are summarized and discussed in the *Elektrische Spektralanalyse chemischer Atome*,[1]

[1] By J. Stark; 138 pp. and 4 plates (Leipzig: S. Hirzel, 1914).

which appeared last summer. The main experimental results are the following.

MAIN EXPERIMENTAL RESULTS

As in the case of the Zeeman effect, the polarization and number of the components depends on whether we look along the field or at right angles to it. The case where the direction of observation is perpendicular to the field is the more important and is called the "transverse effect." The other is the "longitudinal effect."

A. TRANSVERSE EFFECT

1. *Diffuse series of H, He, and Li.—a*) Polarization of components: The components polarized along the field (*p*-components) and those polarized at right angles (*s*-components) do not agree in number, position, or relative intensity in the case of H, but correspond more closely in the case of He and Li (see Fig. 1).

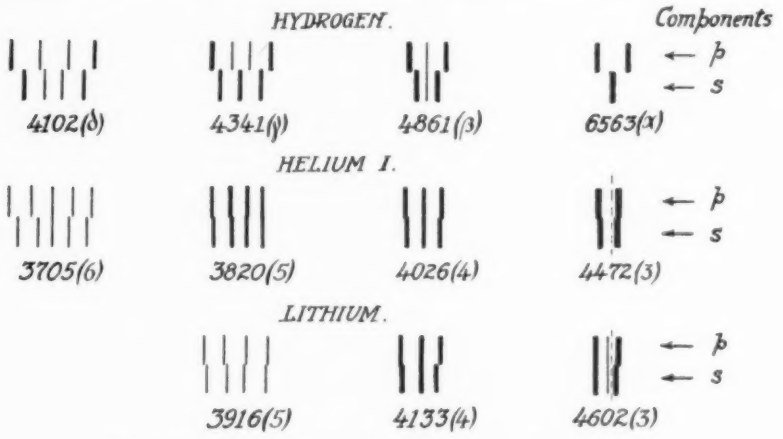


FIG. 1.—Stark effect for various series-lines. Rough analysis

b) Separation of components as a function of field-intensity: Measurements on H and He lines show the separation to be directly proportional to the field.

c) Symmetry of position of components: For H, the components are symmetrical both as to displacement from the original line and as to relative intensity, in the case of light from sources at rest. When the light comes from moving sources (canal rays), the

long-waved components are more or less intense than the short-waved components, according as the field is in the same or opposite direction to the velocity of the sources. Some He and Li lines show a distinct asymmetry both as to displacement and intensity.

d) Resolution of various lines of the same series: Unlike the Zeeman effect, the Stark effect varies from line to line of the same series. Both the number of components and the maximum displacement of the outer components increase regularly with the term-number (see Fig. 1).

e) Relative behavior of corresponding lines of H, He, and Li. There is a rough similarity, especially for the *s*-components of all three, and for the *p*-components of He and Li (see Fig. 1).

2. *Other series of lines.—a*) Sharp main and subordinate series of He and Li: The effect is much smaller than for the diffuse series. The separation, however, increases with the term-number as for the other series.

b) Lines of other elements: Lines of Al, C, Ca, Hg, Mg, Na, and Th have been investigated. The effect was found to be small or practically nil. It appears that series lines of heavier elements are less affected than the corresponding lines of chemically similar elements of less atomic weight. The diffuse series of triplets of Hg show an appreciable effect.

3. *Band lines of H and N.—a*) Earlier observations showed no effect for these lines. Later, however, positive results were obtained for some H band or rather compound lines. Some of these lines are unaffected; others instead of being resolved into components are shifted either toward the red or toward the violet. This merely emphasizes the complexity of this spectrum, in agreement with Dufour's measurements of the Zeeman effect. Whether the shift is proportional to the field or increases more rapidly is as yet undecided.

B. LONGITUDINAL EFFECT

1. *Diffuse series of H and He.—a*) Components are unpolarized.

b) Components agree in displacement and relative intensity with the *s*-components of the transverse effect.

C. WIEN MAGNETIC EFFECT

An electric charge e moving in a transverse magnetic field of strength H, experiences the well-known Lorentz force $e\left[H\frac{v}{c}\right]$ which is perpendicular to both H and v, and is equivalent to an electric force. Wien observed the light emitted by canal rays in a strong magnetic field in a direction at right angles to the velocity of the rays and found a resolution into components precisely like that obtained by Stark with an equivalent electric field.

D. COMBINED STARK AND ZEEMAN EFFECTS

Croze investigated the Zeeman effect for $H\alpha$ in a capillary tube perpendicular to the axis of the magnet and got incomplete polarization and too great a separation of the outer components. These results Stark explains as due to a superposition of the two effects. The interesting fact is that the components were still clearly resolved. More recently Garbasso[1] reports that while Hα is resolved into three components by either an electric or a magnetic field alone, the effect of both combined is a separation into four components, two polarized along the field due to the electric field and two polarized at right angles, due to the magnetic field, the central component due to each being absent.

DETAILS REGARDING THE HYDROGEN COMPONENTS

The mean shift—relative change of frequency per unit field—and the relative intensity of each pair of corresponding components of the various hydrogen series lines have been computed from Stark's measurements and are given in Table I. The means for each pair alone need be considered because of the evident symmetry of the components both as to position and relative intensity. Corresponding measurements agree usually to within 4 per cent for shift and 10 per cent for intensity. In the accompanying figures (Figs. 2 and 3) the relative intensities are indicated by the relative diameters of the circles. Components of the different lines which apparently correspond to each other are numbered alike;

[1] *Physikalische Zeitschrift*, **15**, 730, 1914.

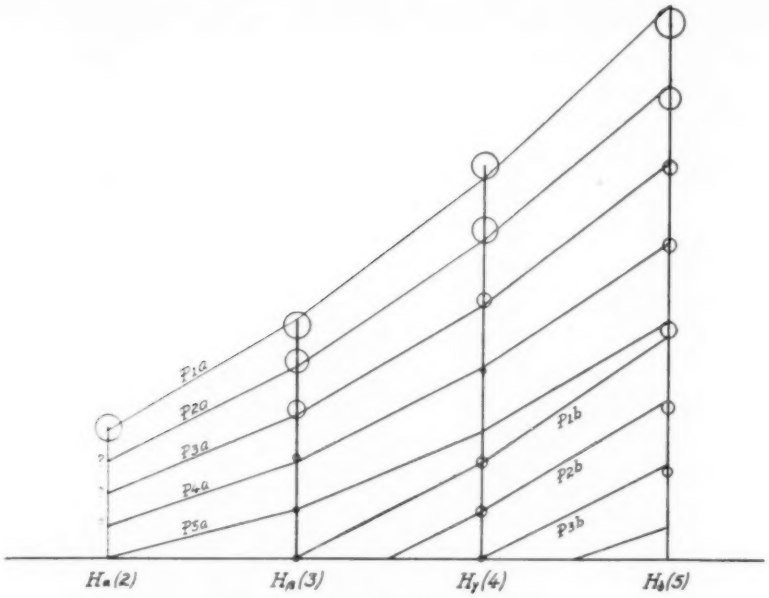


FIG. 2.—Components polarized parallel to the field. Fine analysis

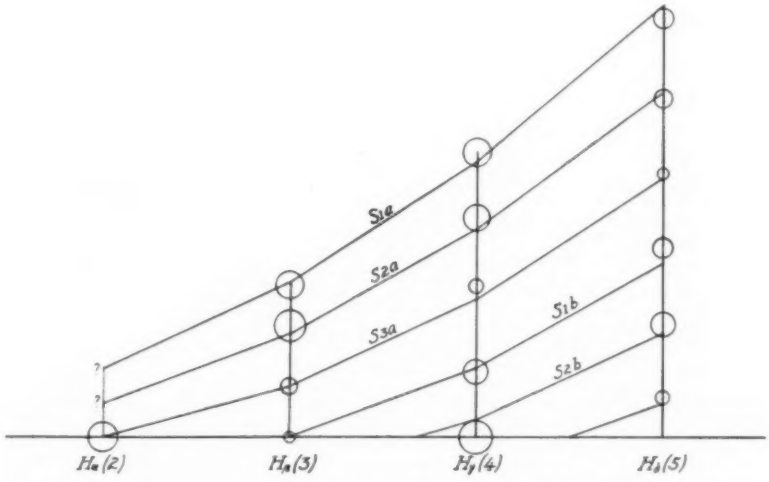


FIG. 3.—Components polarized perpendicular to the field. Fine analysis

those polarized parallel to the field are denoted by *P;* those polarized at right angles to the field are denoted by *S*. Two groups of *P*- and *S*-components are distinguished. The field actually used by Stark was 74,000 volts per cm and the maximum displacements obtained were 11A for Hβ, 17A for Hγ, and 22A for Hδ.

The fine analysis, as was stated above, resolves the few broad components of the rough analysis (shown in Fig. 1) into many more components. Thus the 26 components of Hδ (13 pairs) are blended together so that only 8 (4 pairs) are seen with low dispersion, one pair each for the *Pa*-, *Pb*-, *Sa*-, and *Sb*-components listed in Table I.

TABLE I

Component	$\frac{\Delta n}{nE}\times 10^8$			Relative Intensity		
	Hβ(4861)	Hγ(4340)	Hδ(4102)	Hβ	Hγ	Hδ
*P*1*a*	3.14	5.30	7.21	1.75	1.77	1.90
2*a*	2.66	4.43	6.22	1.56	1.63	1.40
3*a*	2.00	3.50	5.28	1.06	0.79	0.75
4*a*	1.35	2.53(?)	4.24	0.31	0.23	0.81
5*a*	0.66	(?)	(?)	0.19	(?)	(?)
*P*1*b*	0	1.31	3.11	0.10	0.55	0.97
2*b*	.....	0.64	2.06	.....	0.58	0.83
3*b*	.....	0	1.18	.....	0.33	0.67
*S*1*a*	2.04	3.82	5.63	1.71	1.89	1.30
2*a*	1.50	2.96	4.54	2.03	1.74	1.13
3*a*	0.69	2.03	3.53	1.08	0.75	0.66
4*a*	0	(?)	(?)	0.62	(?)	(?)
*S*1*b*	.....	0.88	2.54	.....	1.56	1.22
2*b*	.....	0	1.52	.....	2.18	1.52
3*b*	.....	.....	.53	.....	.....	0.90

Some regularities are immediately evident.

1. The shift for the outer components (*P*1*a*) increases regularly with the term-number. Voigt suggested the formula

$$\frac{\Delta n}{nE}=A(m+1)^2\,; \qquad (1)$$

and the formula

$$\frac{\Delta n}{nE}=B\,m(m+2) \qquad (2)$$

also fits the observations quite closely, as shown in Table II.

2. The difference between the shifts of successive components ($P1a$, $P2a$, $P3a$, etc.) is approximately constant for each line,

TABLE II

Line and Term-Number	Hα(2)	Hβ(3)	Hγ(4)	Hδ(5)	Hε(6)	Mean
$\frac{\Delta n}{nE}$ (observed)$\times 10^8$	1.75	3.14	5.30	7.21	10.4	.....
$\frac{\Delta n}{nE} \div (m+1)^2 \times 10^{-9}$	1.95	1.96	2.12	2.01	2.12	2.05
$\frac{\Delta n}{nE} \div m(m+2) \times 10^{-9}$	2.19	2.09	2.21	2.06	2.17	2.13

increases regularly from line to line with the term-number, and is roughly equal to $P1a$ divided by $(m+2)$, as shown in Table III.

TABLE III

	Hβ(3)	Hγ(4)	Hδ(5)
$P1a-P2a$	0.48	0.87	0.99
$P2a-P3a$	0.66	0.93	0.94
$P3a-P4a$	0.65	0.97(?)	1.04
$P1a \div (m+2)$	0.63	0.88	1.03

We have, then, apparently, $(m+2)$ Pa-components, spaced regularly at a distance of $0.213\times 10^{-8}\, m$ apart. So our formula (2) above may be generalized to include all the Pa-components to

$$(Pa\text{-components})\ \frac{\Delta n}{nE} = 2.13\times 10^{-9}[m(m+2)-m(p-1)] \qquad (3)$$

when p is the number of the component and varies from 1 to $m+3$.

3. Further investigation discloses similar regularities throughout. The positions of the components may all be represented within the apparently rather large experimental uncertainty, by the following equations, in which m stands for the term-number of the series line, and p and s each stand for the number of the component in a group of P- and S-components respectively.

Pa-components:

$$\frac{\Delta n}{nE}=2.13\times 10^{-9}[m(m+2)-m(p-1)] \tag{3}$$

$$\frac{\Delta n}{nE}=2.05\times 10^{-9}[(m+1)^2-m(p-1)] \tag{4}$$

Pb-components:

$$\frac{\Delta n}{nE}=2.13\times 10^{-9}[(m-3)(m+2)-(m-1)(p-1)] \tag{5}$$

$$\frac{\Delta n}{nE}=3.08\times 10^{-9}[(m-3)(m)-(m-2)(p-1)] \tag{6}$$

Sa-components:

$$\frac{\Delta n}{nE}=2.33\times 10^{-9}[m^2-m(s-1)] \tag{7}$$

$$\frac{\Delta n}{nE}=2.05\times 10^{-9}[(m-1)(m+2)-m(s-1)] \tag{8}$$

Sb-components:

$$\frac{\Delta n}{nE}=2.33\times 10^{-9}[(m-3)(m)-(m-1)(s-1)] \tag{9}$$

$$\frac{\Delta n}{nE}=3.08\times 10^{-9}[(m-3)(m-1)-(m-2)(s-1)] \tag{10}$$

The present data are not sufficiently accurate to decide between these alternative equations. For simplicity we should naturally choose either all the odd or all the even as then the number of constants is least and the equations are most closely related. To show how accurately the components may be represented by these equations, full lines have been drawn in Figs. 2 and 3 connecting points computed from the odd equations above, (3), (5), (7), and (9). This set of equations involves only two constants besides integers and gives the position of about forty components with fair approximation. An accurate investigation of the electric resolution of Hα and Hϵ would be interesting to determine whether the new data will fit into the foregoing equations or not.

COMPARISON OF THE EFFECT FOR CORRESPONDING H, He, AND Li LINES

Helium lines have also been studied carefully by Stark, but the results of the fine analysis have not been published. The corre-

TABLE IV

MEAN $\frac{\Delta n}{nE}\times 10^8$

m	2	3	4	5	6
H	1.75	3.14	5.30	7.21	10.4
He I	Small(?)	1.63	3.36	5.20	8.4(?)
He II (parhelium)	Small(?)	1.84	3.63	(?)	(?)
Li	Small(?)	1.31	2.72	4.58	(?)

sponding $P1a$-components have shifts as given in Table IV. These may be represented by the following equations:

Hydrogen: $$\frac{\Delta n}{nE}=2.13\times 10^{-9}[m(m+2)] \qquad (1)$$

Helium I: $$\frac{\Delta n}{nE}=2.66\times 10^{-9}[m(m-1)] \qquad (11)$$

Helium II: $$\frac{\Delta n}{nE}=3.06\times 10^{-9}[m(m-1)] \qquad (12)$$

Lithium: $$\frac{\Delta n}{nE}=2.24\times 10^{-9}[m(m-1)]^{1} \qquad (13)$$

These equations merely serve to emphasize the similarity of the effect for these four diffuse series of lines.

Before considering the significance of these results in connection with atomic structure, Stark shows how this effect is probably related to two other spectral phenomena, (1) the broadening of lines in the case of great vapor- or current-density and (2) the pressure-shift.

RELATION TO THE BROADENING AND PRESSURE-SHIFT OF SERIES LINES

The very fact that it is the so-called "diffuse" series of H, He, and Li which show the Stark effect most markedly points to a

[1] The writer must assume all responsibility connected with the suggestion of equations (2) to (13). They seem obvious enough but are not given by Stark.

relation between broadening and the newly discovered effect. Broadening had not been studied quantitatively, so Wendt carried out a special investigation at Aachen and found that in any series of lines the broadening increases with the term-number in the same manner as the Stark effect. Stark also points out that the broadening is unsymmetrical in the case of those He and Li lines which show an unsymmetrical Stark effect. These facts strongly suggest that *broadening is due to the effect of the electric fields of neighboring atoms on those emitting the light.* However, broadening seems a much more common characteristic of lines than sensitiveness to an electric field, and special hypotheses have to be made to explain the small Stark effect in the case of lines such as the sodium D lines which are very easily broadened. Nevertheless, the suggestion of a relationship between the two phenomena must contain some truth and should prove very fruitful.

Stark also tries to connect the pressure-shift with the *asymmetry* observed in the electric resolution of some lines. In the case of Li and Hg the pressure-shift roughly corresponds, according to Stark, to what would be expected from the dissymmetry of the Stark-effect components as to position and relative intensity. This hypothesis is less firmly grounded than the preceding one, but should also prove stimulating to research in this field.

Astronomers immediately saw in the Stark effect a means of determining the electric fields of the sun and stars. Salet and Millochau, however, found no effect for $H\gamma$ in light from the chromosphere of the sun; and Stark points out how unlikely it is that in an ionized gas, not between electrodes, fields of the order of those used in his experiments should exist. The maximum field possible depends upon the pressure, so that greater fields may be expected in the lower layers of the sun's atmosphere. To study these, the Stark effect for iron and other metallic lines must be known.

Now as to the relation of the Stark effect to atomic structure. As Stark says, the importance of the effect lies in the fact that this relation is so intimate. Without a more or less definite hypothesis as to atomic structure, it cannot be understood at all. Its details are new facts to be explained, new and most important criteria for judging proposed atomic models; but the results are also

directly suggestive. The data have been summarized above; the suggestions are, briefly, the following.

1. *Asymmetry of intensity in the case of a moving source.*—Stark interprets this result as meaning that the electrons emitting the more intense component are on the forward end of the moving atom and emit more light as a result of collision with gas molecules than do electrons at the back end of the atom. If a train of waves is emitted by each electron, this involves the assumption that the position of the active electrons with respect to a plane perpendicular to the velocity of the canal rays is unchanged during the emission of any one component; that is, either they vibrate about fixed positions of equilibrium or they rotate in planes perpendicular to the velocity of the atom.

2. *Croze's results and the Wien experiments.*—The velocity of the electrons affected by the magnetic field consists of two parts, that due to the motion of the atom as a whole, and its velocity with respect to the atom. The latter is undirected with respect to the magnetic field. Stark argues from the fact that Croze obtained distinctly separated components (as did Garbasso also) that the speed of the electrons inside a hydrogen atom cannot exceed 10^6 cm per second. Further and more accurate observations on the combined Zeeman-Stark effect will prove most important if they lead to an accurate determination of this internal electronic speed.

3. *The number of hydrogen components.*—Stark is inclined to overemphasize the complexity of the analysis effected by an electric field. Yet, though the components are all probably quite simply related, their number and sharpness indicate that each hydrogen line may be emitted by an electron under more than a dozen distinct sets of circumstances—distinct at least in that they are differently affected by an electric field. Stark suggests a ring of electrons, each emitting the same line when the electric field is zero, each equally affected by a magnetic field, but each differently affected by an electric field. The sharpness of the components necessitates the assumption that the ring is fixed in orientation and that the emission of light is due to the vibration of the electrons about a position of equilibrium. But since the components are not independent, it does not seem that they each do demand a

separate electron as their source any more than the numerous band lines of nitrogen require an equal number of electrons in the nitrogen molecule. Yet the hydrogen atom must be a much more complex affair than any of the suggested atomic models.

The other important clues to atomic structure may now be mentioned as a basis for a brief summary of our present vague conception of the atom.

4. *Zeeman effect.*—This indicates that the emission of the series-lines associated with various elements is due to the acceleration of electrons in the atoms.

5. *Scattering of α and β rays by matter; production of very penetrating H rays by bombardment with α rays.*—Such experiments strongly support Rutherford's nuclear conception of the atom. Whether the deflection is due to the magnetic or to the electric forces associated with the nucleus, the concentration of the nucleus into an extremely small volume seems a necessary hypothesis. The charge computed for the nucleus comes out about $+\frac{1}{2}Me$, where M is the atomic weight.

6. *Characteristic X radiation.*—Moseley's results suggest that the fundamental characteristic atomic constant is the atomic number rather than the atomic weight. This atomic number increases by one as we pass from element to element in the periodic table and is probably equal to the nuclear charge measured in units equal in magnitude to the electric quantum.

7. *Doppler effect for canal rays.*—Stark has determined that the diffuse series of both hydrogen and helium I are emitted by atoms which have lost one electron, while the diffuse series of helium II (parhelium) is emitted by atoms which have lost two electrons. But a helium atom minus two electrons is an alpha particle; and it seems certain that an α ray is merely a helium nucleus unattended by detachable electrons. It seems clear, then, that *the nucleus must contain the electrons which emit the series lines.*[1]

While these clues are not at all conclusive, they suggest quite definitely the following vague picture of a hydrogen atom. A neutral hydrogen atom consists of a small nucleus with a charge

[1] This obvious conclusion from Stark's experimental results is, rather strangely, not mentioned by him.

$+e$, about which one electron revolves in dynamic equilibrium. Such a neutral atom cannot emit the Balmer series; it must first lose its electron by collision or otherwise. The Balmer series is emitted by electrons in the nucleus, vibrating about positions of static rather than dynamic equilibrium. Of the forces holding the parts of the nucleus together we know nothing except that apparently, according to Voigt, the forces involved are not isotropic, though they may be quasi-elastic. A swift electronic ray passing near the nucleus causes the emission of characteristic X radiation; while the shock of ionization results in the emission of light whose frequency may be affected by external magnetic and electric fields. Whether or not the nucleus contains magnetons we have no evidence upon which to base an opinion. When two atoms combine to form a molecule, the mutual influence of the nuclear fields changes the frequencies of vibration so that the spectrum emitted is quite different.

Now for the Bohr atom. How does it fare when tested by the Stark effect? Bohr does apparently succeed in relating the constant of the Balmer series to the Planck constant. But his assumption that the series lines are emitted by the single rotating electron of the hydrogen neutral atom is directly contrary to Stark's experimental result, which is one of the most certain clues we have. And as Stark says, such agreement with experiment as Bohr's theory does show "verliert ihre Bedeutung völlig dadurch, dass die Theorie wesentliche Züge der elektrischen Zerlegung der H-Serienlinien qualitativ nicht richtig wiederzugeben vermag" (p. 119).

In connection with the quantum theory in general, the following quotations may be of interest.

> Als einer der ersten Anhänger der Planckschen Quantenhypothese möchte ich mir ihr gegenüber folgendes Bekenntnis erlauben. In mehreren Fällen scheint mir diese Hypothese in einem schwer lösbaren Widerspruch mit der Erfahrung zu stehen. Darum misstraue ich den Anwendungen, welche ich von der Planckschen Hypothese zur Deutung einiger Erscheinungen gemacht habe [p. 115]. . . . . Diese Folgerung über eine obere Grenze für die lichtschwingende Geschwindigkeit der Serienelektronen scheint mir eine ernsthafte Schwierigkeit für die Plancksche Lichtquantenhypothese mit sich zu bringen. . . . . Will man also die Plancksche Hypothese gegenüber der vorstehenden

Folgerung halten, so muss man eine weitere Hypothese zu Hilfe holen. . . . . Indes würde eine solche Hilfshypothese in meinen Augen mehr eine Belastung der Planckschen Hypothese mit Unerklärtheit bedeuten, und als Experimentalphysiker möchte ich dann lieber auf die Plancksche Hypothese selbst verzichten als so unbestimmte Hilfshypothesen in Kauf nehmen [p. 113].

In conclusion I should like to call the attention of theoretical physicists to the great field of unexplained intra-atomic phenomena to which the nuclear conception of the atom might be applied. Such investigation should lead either to a better understanding of such phenomena or to important modifications of the hypothesis or to both.

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THE TUBE-ARC SPECTRUM OF IRON AND A COMPARISON WITH DISSYMMETRIES IN SPARK SPECTRA[1]

By ARTHUR S. KING

In previous papers,[2] the writer has described some of the phenomena of the "tube-arc." To produce this light-source, the tube used in the electric furnace is filed thin at the middle of its length, so that when the voltage is applied, the tube quickly burns apart, forming an arc carrying a very large current at low voltage. The spectrum shows a high intensity of the enhanced lines of metals, the spark spectrum of carbon, and the brighter hydrogen lines, together with an interesting difference in the intensity of the lines of various elements across the diameter of the tube when this ring-shaped arc is viewed axially.

Another feature mentioned in the former papers is a marked dissymmetry in the structure of certain tube-arc lines. This was not studied in detail, but it was shown that the dissymmetry is very marked for many lines which are symmetrical in the furnace spectrum and approximately so in the ordinary arc in air.

Recently a much larger transformer was installed in the Pasadena laboratory, giving improved facilities for work with the tube-arc. Its capacity is 100 kw and the voltage may be varied by 5-volt steps from 5 to 50 volts. With this apparatus, tube-arcs have been operated which consumed as high as 70 kw just after the rupture of the tube. An initial energy of about 40 kw, however, has given the best results, the exposure being made while the current fell from above 1000 to about 600 amperes.

The second order of a 4-inch plane grating was used in the vertical spectrograph, with an objective of 30 feet focal length, giving a linear scale of about 1 mm = 0.9 A. The interior of the tube, at the point where the arc was to form, was focused on the

[1] *Contributions from the Mount Wilson Solar Observatory*, No. 103.

[2] *Mt. Wilson Contr.*, Nos. 65, 73; *Astrophysical Journal*, **37**, 119; **38**, 315, 1913.

slit, so that the spectrum registered the radiation along the vertical diameter of the ring of arc when the tube burned apart. The arrangement of the tube and the inclosing jacket of graphite was similar to that in the earlier experiments, except that the point of break was located by simply filing a deep groove around the tube at its middle. The gap between the ends of the tube, after the arc had ceased, usually measured 10–15 mm above and 30–40 mm below, but was occasionally longer. The time of action of the arc was generally 30–40 seconds.

The present paper will consider the leading features of the tube-arc spectrum of iron, these being, first, the displacements resulting from the dissymmetry shown by many of the stronger lines, the degree of this dissymmetry being clearly connected with the classification of the lines in the furnace spectrum and in that of other sources, and, second, the enhancement of certain types of lines. The peculiarities in structure of tube-arc lines are found to be very similar to those exhibited by the spectrum of the condensed spark. A comparison of typical iron lines in tube-arc and spark will be given, together with a brief description of the variable dissymmetries found in other spark spectra, especially that of titanium.

DISSYMMETRIES OF IRON LINES IN THE TUBE-ARC

A study of the tendency of various light-sources to render lines unsymmetrical has the twofold object of showing what features in the light-source produce these dissymmetries and the degree to which various lines are subject to such disturbing influences. The tube-arc shows effects in a very pronounced degree which are present in a more or less incipient state in the ordinary arc in air, especially in the region near the negative pole. Such dissymmetries are naturally most conspicuous in the case of reversed lines, and a large number of iron lines are given in reversal by the tube-arc. Few of these show a fully symmetrical reversal when their intensities are such that they are satisfactory for examination. A few low-temperature lines to the violet of λ 4000 reverse so widely in the tube-arc that they are practically absorption lines, and little can be said regarding the relative strength of their edges. The iron lines showing distinct self-reversal usually have the red side

stronger than the violet, and a large variability appears in the amount of the dissymmetry.

Lines of small or moderate dissymmetry toward the red.—In Table I, a list of lines is given whose dissymmetry of reversal does not

TABLE I

IRON LINES SHOWING SMALL OR MODERATE DISSYMMETRY TOWARD THE RED IN THE TUBE-ARC

λ (Rowland)	Ratio of Violet and Red Sides	Furnace Class	Pressure Class	Pressure Group
3887.196.....	2:3	I	1	*b*
3888.671.....	2:3	II (I)	1	*b*
3906.628.....	2:3	I	1	*b*
3969.413.....	3:4	II	1	*b*
4005.408.....	3:4	II	1	*b*
4045.975.....	3:4	II	1	*b*
4063.759.....	3:4	II	1	*b*
4071.908.....	3:4	II	1	*b*
4132.235.....	2:3	II	1	*b*
4144.038.....	3:4	II (I)	1	
4202.198.....	3:4	II	1	*b*
4250.945.....	3:4	II	2	*b*
4271.934.....	3:4	II	1	*b*
4282.565.....	5:6	I (II)	1	*b*
4294.301.....	5:6	I	2	*b*
4308.081.....	2:3	II	1	*b*
4325.939.....	2:3	II	1	*b*
4376.107.....	3:4	I	3	*a*
4383.720.....	2:3	II	1	*b*
4404.927.....	2:3	II	1	*b*
4415.293.....	2:3	II	1	*b*
4427.482.....	2:3	I	3	*a*
4461.818.....	5:6	I	3	*a*
5227.362.....	9:10	II	4	*a*
5269.723.....	9:10	I	1	*a*
5270.558.....	9:10	II	4	*a*
5328.236.....	9:10	I	1	*a*
5371.734.....	9:10	I	1	*a*
5397.344.....	9:10	I	4	*a*
5405.989.....	9:10	I	4	*a*
5429.911.....	9:10	I	4	*a*
5434.740.....	9:10	I	4	*a*
5447.130.....	9:10	I	4	*a*
5455.834.....	9:10	I	4	*a*

exceed a moderate amount, with the red side not more than twice as strong as the violet. Table II contains lines which reverse very unsymmetrically. Some of the latter show but a trace of the violet side of the line on the plate. The second columns of Tables I and II give the estimated ratios of the two sides of the reversal.

TABLE II

IRON LINES SHOWING LARGE DISSYMMETRY TOWARD THE RED IN THE TUBE-ARC

λ (Rowland)	Ratio of Violet and Red Sides	Furnace Class	Pressure Class	Pressure Group
4187.204	1:6	II (III)	.....	.....
4187.943	1:6	II (III)	.....	.....
4198.494	1:6	III	.....	.....
4227.606	1:8	III	5	*d*
4233.772	1:6	III	5	*d*
4236.112	1:6	II (III)	5	*d*
4250.287	1:6	III	5	*c*
4260.640	1:6	III	2	*c*
4271.325	1:6	III	.....	.....
4299.410	1:6	II	5	*d*
4528.798	1:4	II	4	*c*
4859.928	1:8	III	5	*c*
4871.512	1:8	III	5	*c*
4872.332	1:8	III	5	*c*
4890.948	1:8	III	5	*c*
4891.683	1:8	III	5	*c*
4919.174	1:8	III	5	*c*
4920.685	1:8	III	5	*c*
4957.480	1:8	III	5	*c*
4957.785	1:8	III	5	*c*
5233.122	1:6	III	5	*d*
5324.373	1:6	IV	5	*d*
5586.991	1:6	IV	5	*d*
5615.877	1:6	IV	5	*d*

In some cases these are based on the curves of the Koch microphotometer, but eye-estimates are sufficiently accurate for classification, which is the main object of these tables. The third column gives the class in which the line is placed in the electric-furnace study[1] made by the writer. Later experience with the furnace spectra has slightly modified the method of classification, and the numbers given in parentheses for a few lines denote the class in which the line would probably fall if the classification were revised. The fourth and fifth columns contain the class and the group in which the line is placed by Gale and Adams[2] according to its appearance under pressure and to its pressure displacement, respectively.

The material presented in Tables I and II shows the following relations between the amount of dissymmetry imparted by the

[1] *Mt. Wilson Contr.*, No. 66; *Astrophysical Journal*, **37**, 239, 1913.

[2] *Mt. Wilson Contr.*, No. 58; *Astrophysical Journal*, **35**, 10, 1912.

tube-arc and the behavior of the lines in the furnace and under pressure:

1. Lines of small and moderate dissymmetry of reversal belong in the furnace Classes I and II, those most nearly symmetrical being as a rule among the "flame" lines of Class I. These are all lines occurring at low temperature, the rate of increase in strength with rise of temperature being more rapid for the lines of Class II.

2. Lines which are strongly unsymmetrical in their reversal in the tube-arc are with few exceptions in Classes III and IV. These require a higher temperature for their initial appearance and increase rapidly in strength as the temperature rises.

3. The connection with the behavior of the lines under pressure is very definite. With two exceptions, all lines in Table I are given as symmetrical in appearance under pressure (Classes 1, 3, and 4), and have small or moderate displacements (Groups *a* and *b*). Those in Table II are made unsymmetrical by pressure (Classes 2 and 5), and show large displacements (Groups *c* and *d*).

Lines displaced toward the violet in the tube-arc.—In the green-yellow an important group of lines is found, the strongest of which are λλ 5365.069, 5367.669, 5370.166, 5383.578, 5404.357, 5411.124, 5415.416, 5424.290. The tube-arc gives these lines very strong, diffuse, and nearly symmetrical, a slight shading appearing on the violet side. By measurements to be described later in the paper, these lines were found to give decided displacements toward the violet. In the furnace these lines are to a certain extent in a class by themselves, since no other lines as strong in the iron arc are so difficult to obtain in the furnace. They appear very faintly at high temperature and are an extreme type of Class V lines.

No reversed iron lines with the violet side strongest have been found, but two mportant cases of this dissymmetry occur in the H and K lines of calcium, which are found on several tube-arc plates of the iron spectrum. In the former paper[1] on the tube-arc, these lines were mentioned as symmetrical, but the greater power available in the later experiments gives them in every case with the violet side stronger, about in the ratio 6:5. The available pressure

[1] *Mt. Wilson Contr.*, No. 73; *Astrophysical Journal*, **38**, 315, 1913.

measurements for H and K indicate that they are displaced toward the red by pressure, so that they appear to present an exception to the general correspondence between the two effects.

Relation to pole-and-center differences in the iron arc.—When a plane-grating spectrograph is used for the observation of the ordinary arc spectrum, the image of the arc from pole to pole being projected on the slit, some lines of iron are found to remain nearly symmetrical from center to pole of the arc and others to become decidedly unsymmetrical near the pole. These differences are being studied in detail by St. John and Babcock. Without giving an extended comparison, it may be stated here that the dissymmetries shown by the tube-arc lines are of the same nature as for corresponding lines in the ordinary arc, but are greatly magnified in amount. This is true also for the lines considered in the last paragraph, which widen toward the violet near the pole of the arc. A comparison by Royds[1] of the pole and center of the arc gave considerable displacements toward the violet for these lines. Another group of lines in this region, found by Royds to give negligible displacements, is included among the tube-arc lines in Table I, while still others showing polar displacements toward the red are in Table II.

Micrometer measurements on unsymmetrical lines.—The group of strong green lines near λ 4900 affords an interesting example of the sort of wave-length measurements that are given by lines of this kind, and also of the relation of the measured displacement to the intensity of the line in question. These lines are in the same furnace class, also in the same pressure class and group. In the tube-arc they are all very unsymmetrical, the violet side of the reversal usually being so faint as to show merely as a shading off on that side, but in the case of two of the group, λλ 4891.683 and 4920.685, the strength of the lines was sufficient to show both sides of the reversal distinctly, so that the measuring microscope could be set on the reversal itself. For the other lines, the maximum was well enough defined to give closely concordant sets of measurements, but these settings were in reality chiefly on the red side of the partially reversed line. An arc spectrum on the same plate given

[1] *Kodaikanal Observatory Bulletin*, No. 40, 1914.

by the center of a 6-ampere arc was measured for comparison. The reference line in each case was λ 4891.683, this being clearly reversed in the tube-arc spectrum. These measurements are given in Table III. The small negative displacement of λ 4920.685

TABLE III

Å	Intensity	Displacement Tube-Arc − Arc
4859.928	8	−0.041
4871.512	25	+0.076
4872.332	12	+0.062
4878.407	5	+0.035
4890.948	15	+0.071
4891.683 (reversal)	30	0.000
4903.502	3	+0.028
4919.174	12	+0.074
4920.685 (reversal)	35	−0.004

is within the error of measurement for lines of this quality. The measured displacements of the others show a rough but distinct relation to the strength of the line. The effect clearly increases with the absolute width of the line, while the example shows the extent to which measured wave-lengths of such sensitive lines may be disturbed in the spectrum of a source of this kind.

Use of the registering micro-photometer.—This brings us to the generally recognized difficulty of making micrometer settings on unsymmetrical lines. One must either set on the reversal, if there is such, in which case no account is taken of the dissymmetry of the sides, or on the position of maximum density, which may well be only one side of a partially reversed line. The Koch microphotometer is of much assistance in this respect. Its use in registering the density-curves for various types of emission lines was illustrated in a previous paper.[1] The large apparatus recently constructed here serves to register the structure of individual lines and also to measure the wave-length interval between lines. If one or both of the lines are unsymmetrical, the position of the ordinate which best represents the maximum of each line must be decided upon. For most of the reversed tube-arc lines, the dissymmetry is chiefly at the top of the curve. Examples are shown in

[1] *Mt. Wilson Contr.*, No. 77; *Astrophysical Journal*, **39**, 213, 1914.

Fig. 1 of two iron lines in different stages of reversal. The wave-length of the corresponding arc line is given closely by the minimum of the reversal, while the maximum of the unsymmetrical line is obtained by producing the slopes of the curves as shown, the ordinate of this maximum being, to a close approximation, midway between the two sides of the curve. If the curve as a whole is very one-sided, owing to shading of the spectrum line, it is more difficult to determine the ordinate for use in a wave-length measurement.

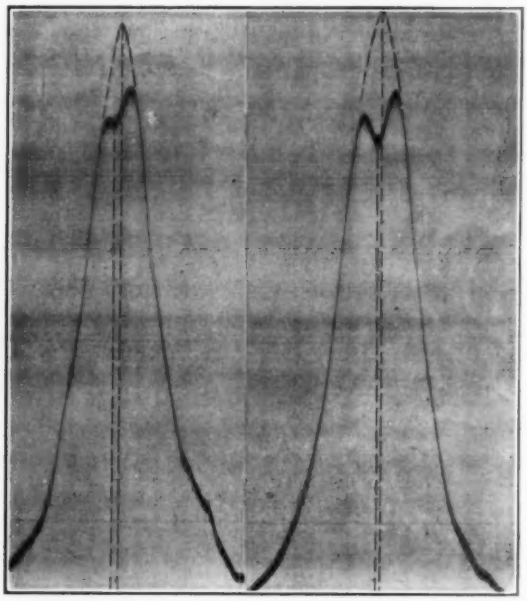


FIG. 1.—Curves of reversed iron lines showing different degrees of dissymmetry in the tube-arc.

Following the plan just outlined, an attempt has been made to measure the displacing action of the tube-arc by obtaining the distance between the centers of pairs of density-curves, one curve being for one of the highly unsymmetrical lines given in Table II, the other for a line, usually from Table I, which could be considered as giving an ordinate practically undisplaced, this ordinate being either that of the reversal of the slightly unsymmetrical line or of its maximum if narrow and unreversed. The curves were registered on direct and reversed runs of the screw to eliminate possible

errors due to inertia in the instrument, which proved, however, to be extremely small. Curves were similarly made for arc lines on the same plate, the portion of the line given by the center of the arc being registered.

A further purpose in measuring these lines was to observe the effect of large differences in the quantity of iron vapor present in the tube-arc. An inspection of photographs made for large and small vapor densities showed the magnitude of the dissymmetry to vary greatly with the strength of the line. With a very small quantity of iron vapor, strong lines such as λ 4383.720 are reversed with the usual degree of dissymmetry; while lines less intense, including many of those which are very unsymmetrical with much vapor present, appear fairly sharp. The question is, Are these weaker lines moved out of their position by the tube-arc to the same degree that they are when strong, or is the effect dependent on the strength of the line? Evidently only a comparison of the distances between the density-curves can decide this question.

TABLE IV

VARIATION IN WAVE-LENGTH OF TUBE-ARC LINES WITH VAPOR-DENSITY

UNSYMMETRICAL LINE	STANDARD LINE	DISPLACEMENT, TUBE-ARC − ARC	
		Low Vapor Density	High Vapor Density
4187.204.....	4185.058	+0.009	+0.019
4187.943.....	4185.058	+0.009	+0.015
4250.287.....	4250.945	−0.002	+0.029
4260.640.....	4271.934	+0.013	+0.040
4271.325.....	4271.934	+0.008	+0.035
4299.410.....	4294.301	+0.001	+0.036

Displacements toward the red.—The values in Table IV give the displacement of the center of density of the unsymmetrical line with reference to a neighboring line taken as standard. Thus a positive displacement indicates that the given line is toward the red with respect to its position in the arc measured from the same standard. λ 4185.058, used as standard for the first two lines, is a Class III line in the furnace and, though narrow, probably suffers some displacement in the tube-arc. The curves of the last three lines in the table were the most satisfactory for measurement.

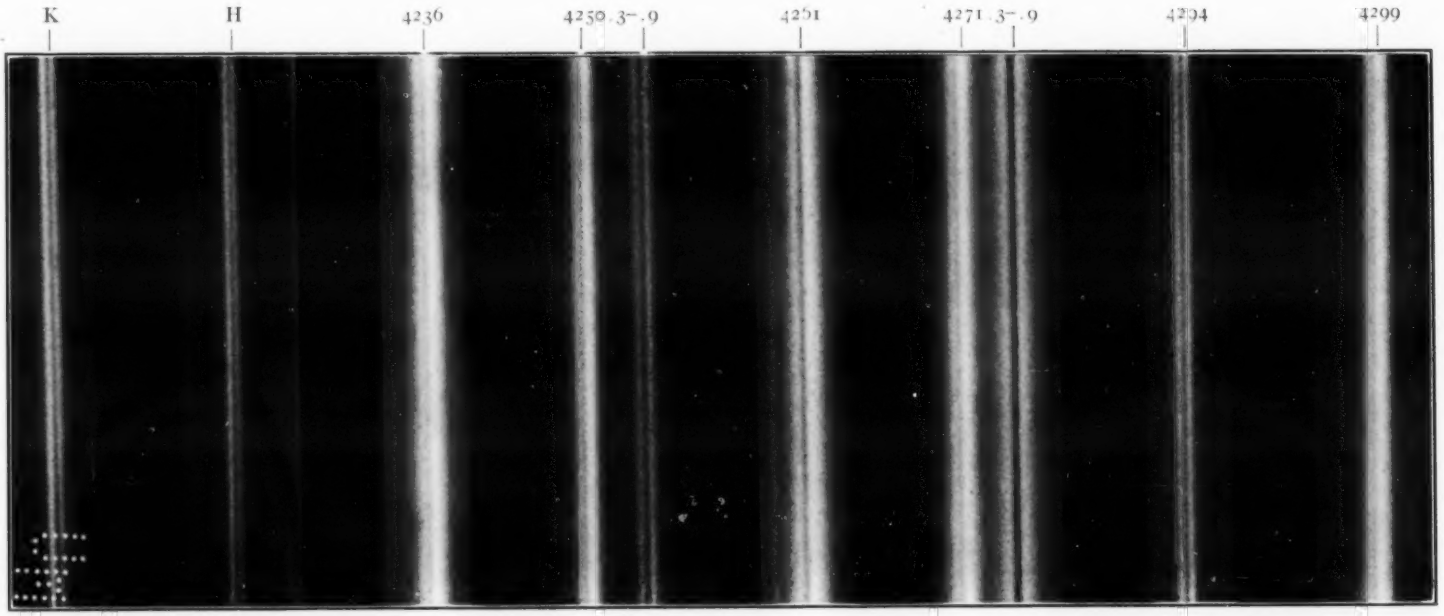
The last column of Table IV gives the magnitude of the displacement measured by the micro-photometer when the tube-arc line shows large dissymmetry; while the third column shows that this displacement becomes small when the width of the line is decreased by low vapor-density. As was previously noted, the tube-arc under the latter condition is still able to produce decided dissymmetry in strong lines such as λλ 4308, 4325, 4384, 4415. How far this effect may be due to differences in vapor-density, strictly speaking, will be discussed later; but evidently the dissymmetry of tube-arc lines does not depend entirely on the strength of the discharge conditions. If it did, the amount of measured displacement to be expected for a line in any source could be calculated from the strength of the enhanced lines in that source; but the effect is complicated by conditions attendant on the amount of vapor present.

The dissymmetries exhibited by some tube-arc lines are shown in Plate VII. First are the calcium lines K and H, which are reversed with the violet side stronger. They appeared thus on several plates which showed the stronger iron lines maintaining their usual dissymmetry toward the red. The iron lines shown are λ 4236.112, highly unsymmetrical, λλ 4250.287 and 4250.945, of large and small dissymmetry respectively, λ 4260.640, showing large dissymmetry, with two satellites on the violet side, λλ 4271.325 and 4271.934, similar to the pair at λ 4250, and λλ 4294.301 and 4299.410, showing a marked contrast in structure.

Plate VII is supplemented by the density-curves in Fig. 2, these being for the same lines as are shown in the plate, with the addition of the iron lines λ 3969.413 (from the same plate as the adjacent H line) and λ 4308.081, made from a plate taken with low vapor-density in the tube-arc.

Displacements toward the violet.—Four of the strong lines in the green-yellow described on p. 377 have been studied with the micro-photometer, the distances being measured in both tube-arc and arc between the curves of these lines and those of standard "flame" lines which reverse almost symmetrically in the tube-arc and may be regarded as probably undisplaced by this source. The arc-curves were made in each case for the part of the line

PLATE VII



UNSYMMETRICAL TUBE-ARC LINES FROM THE SPECTRA OF CALCIUM AND IRON

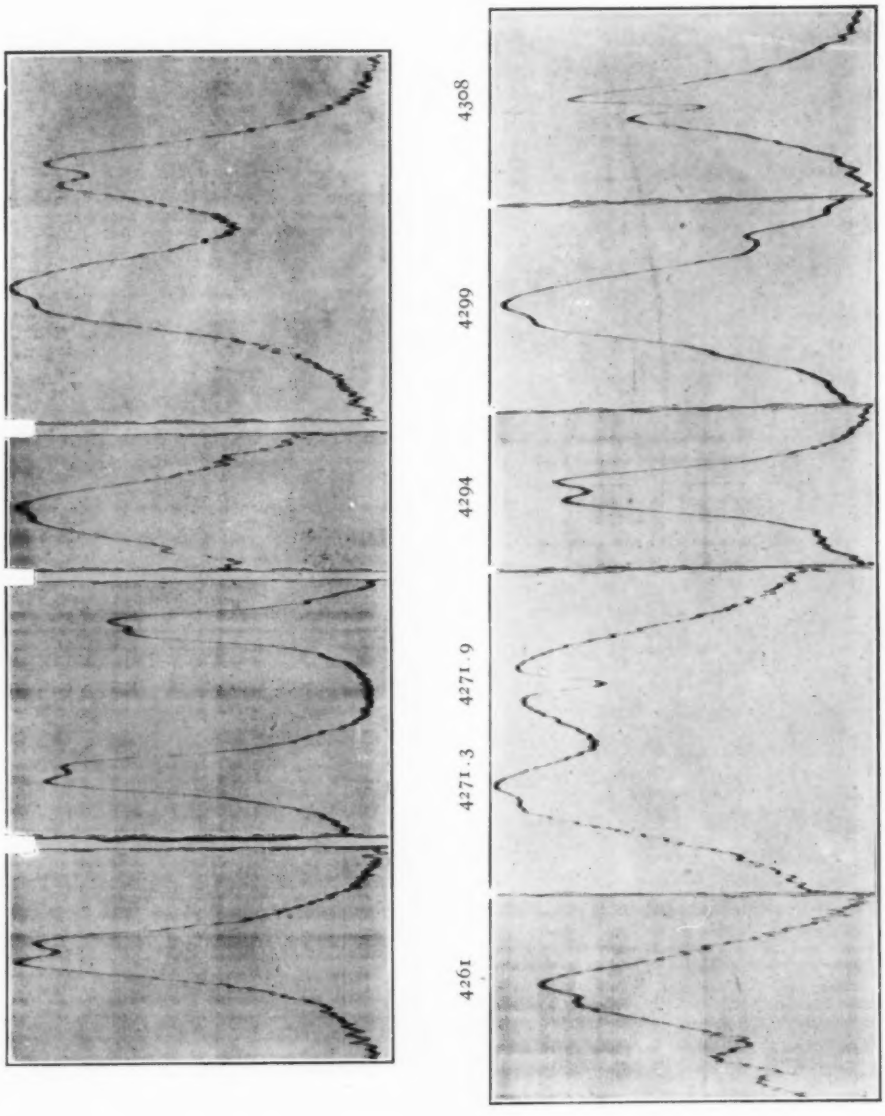


FIG. 2.—Density-curves of tube-arc lines, showing varying degrees of dissymmetry

given by the central region of the arc. The results are given in Table V.

TABLE V

TUBE-ARC LINES DISPLACED TOWARD THE VIOLET

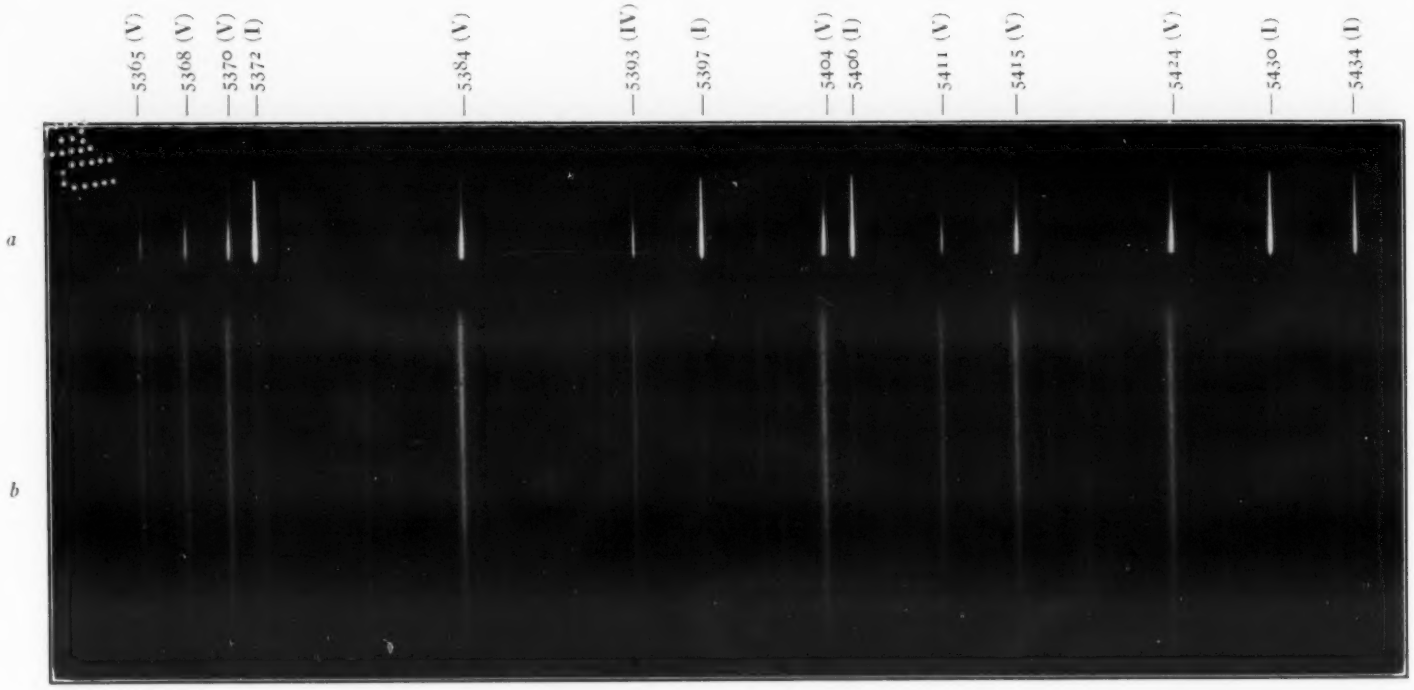
λ (Rowland)	Standard Line	Displacement
5367.669	5371.734	−0.036
5370.166	5371.734	−0.027
5411.124	5405.989	−0.056
5415.416	5405.989	−0.094

These displaced lines are unreversed and the measurements were taken well up on the curve, where it is nearly symmetrical. The bottom of the curve shows a shading toward the violet which would increase the displacement if it were taken into account; but the method employed measures as nearly as possible the position of the strongest part of the line. The displacement of λ 5415.416, the strongest of the group, is seen to be very large, an effect similar to that noted for the lines near λ 4900 (see p. 378), where the measured displacement, in a group of lines showing the same behavior, was found to increase with the strength of the line. The displacements given in Table V are the means of two sets of curves having different scales, made by changing the speed ratio between the negative and the registering plate. The two sets gave almost identical results, and while no high degree of accuracy can be claimed for the absolute values of the displacements, there can be no question that any method of measurement would give displacements toward the violet of considerable magnitude for the centers of density of these lines.

LINES INTENSIFIED IN THE TUBE-ARC SPECTRUM

It is in harmony with the general resemblance of the tube-arc spectrum to that near the pole of the ordinary arc that the enhanced lines of iron should be brought out strongly and a decided intensification be given to those usually classed as "nebulous" in wavelength tables and thus denoted by the writer in the paper on the furnace spectrum. With few exceptions, they belong in Class V, being absent or extremely faint in the furnace spectrum. In the

PLATE VIII



THE SPECTRUM OF IRON

(*a*) In ordinary arc, (*b*) in tube-arc, showing the high intensity of lines in the higher furnace classes (indicated after the wave-length), as compared with the "flame" lines of Class I

ordinary iron arc, these lines are much stronger in the highly luminous part near the negative pole. In the tube-arc, they are very strong, the well-known group in the green-yellow from λ 5365.069 to λ 5424.290 dominating the spectrum in this region. This condition is illustrated by Plate VIII, which shows the tube-arc spectrum with that of the ordinary iron arc for comparison. The strong lines of Class I are scarcely visible, but this is partly due to their being reversed for the greater part of their width, the edges of the reversal being almost symmetrical.

THE TUBE-ARC SPECTRUM IN THE ULTRA-VIOLET AND RED

The investigation of iron in the tube-arc has covered the spectrum from λ 3600 to λ 6600. At the violet end of this range, dissymmetries are numerous, but no features of special interest were observed. The stronger lines reverse with the red side stronger, the dissymmetry being moderate in amount, similar to the lines listed in Table I. The region from λ 5700 to λ 6600 required the first order of a very bright grating, and few deviations from the usual arc spectrum appeared. The stronger lines remained sharp, only a few showing shading toward the red. The diffuse lines were intensified, and the enhanced lines appeared as in other portions of the spectrum.

DISSYMMETRIES IN THE SPARK SPECTRUM

The writer has at intervals during several years photographed the spectrum of the spark under conditions giving a highly disruptive discharge. A powerful transformer spark with large condenser was used, the spark terminals being bluntly pointed rods of iron held in massive brass cylinders for cooling. After the discharge started, a series spark-gap was lengthened until the transformer was just able to maintain an exceedingly noisy spark. Comparison arc spectra were made on each plate by placing an arc in the position formerly occupied by the spark, leaving the lens system undisturbed. Sometimes the position of the spark line with reference to that of the arc was tested by means of the occulting screen, exposures with the arc being made before and after the spark exposure. For a large number of photographs a long slit was used,

on which the image was projected with the axis of the spark at right angles to the slit. The middle of the spectrum line then registered the radiation from the interior of the spark, together with that from the outer vapor in the line of sight; while toward its ends the spectrum line was given by light from the outer vapor alone. Lines sensitive to reversal were frequently reversed almost to the point where the tip faded from the plate. The more striking features observed were as follows:

1. Dissymmetries were found to be very frequent in the spark spectrum and to vary greatly in magnitude for different lines.

2. The relative sensitiveness to dissymmetry among the lines of the spark appears to be quite the same as that observed for corresponding lines in the tube-arc spectrum.

3. In the spark spectrum of iron, two classes of lines, both unreversed in the spark, show no dissymmetry. These are the flame lines (furnace Class I) and the enhanced lines. As will be noted later, exceptions to this rule are found in other spectra when such lines are reversed.

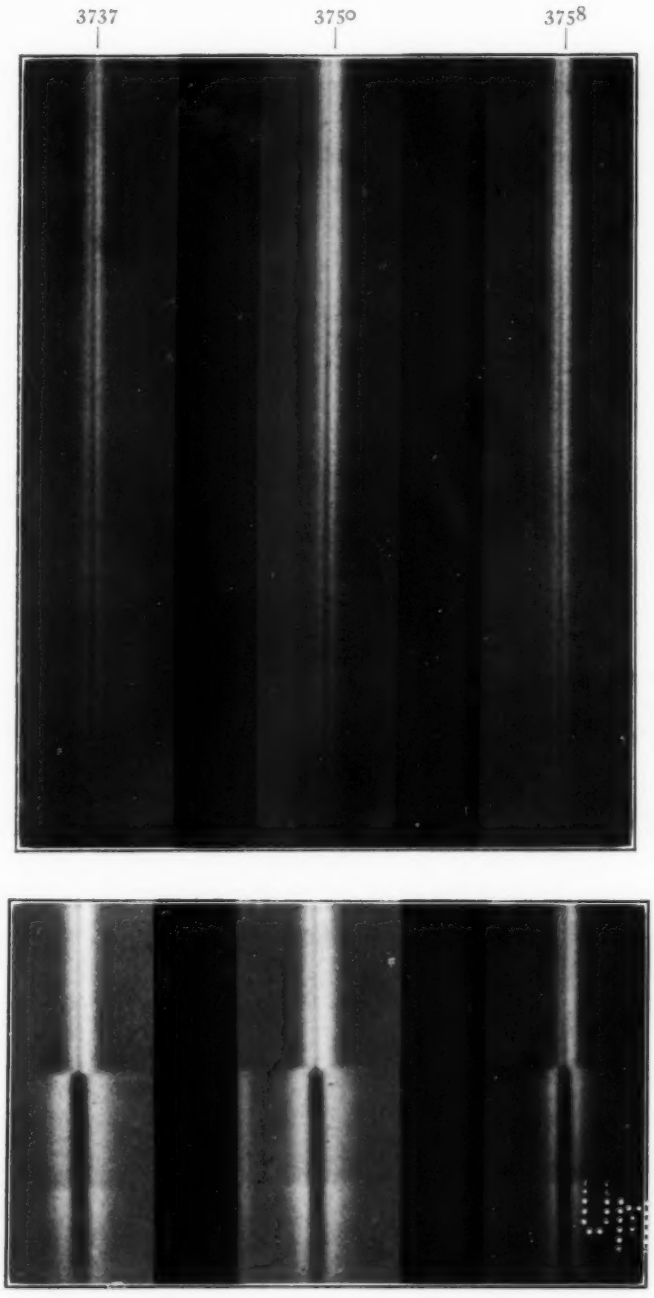
4. The stronger arc lines in the blue and violet, usually of Class II, when photographed with a long slit, show large dissymmetry of the reversal at the middle of the line, the red side being the stronger. Receding from the central position reduces this dissymmetry as the interior vapor of the spark becomes less effective, until at the ends of the long line approximate symmetry is attained.

5. When adjacent spectra of the arc and of the core of the spark are made by means of the occulting screen, the position of the reversal is found to coincide closely in the two spectra, thus indicating that the outer vapors of the spark which cause the reversal give a line in the position of the arc line. This conclusion was arrived at by Kent,[1] who compared the lines given by the arc and spark in a concave-grating spectrum.

The features described in Nos. 4 and 5 are illustrated in Plate IX. In the upper section are enlargements of three reversed iron lines, each showing half of the length of the line photographed with the long slit across the spark-image. The unsymmetrical line given by the core is seen to change to a symmetrical line given by the

[1] *Astrophysical Journal*, **22**, 182, 1905.

PLATE IX



IRON LINES SHOWING DISSYMMETRY IN THE DISRUPTIVE SPARK

a. Half of long line photographed with the slit at right angles to axis of spark.

b. Comparison of spark line (above) with arc line.

outer vapor. In the lower section of the plate, the same lines are shown as photographed by means of the occulting screen, the line given by the core of the spark having below it two exposures of the arc line made before and after the spark exposure respectively. The contrast in symmetry between the arc and spark lines is seen, and also the continuity of the reversal for the two sources.

The effect is further illustrated by the micro-photometer curves of Fig. 3. These show the structure of λ 3737.281 at the middle and near the end of the long spark line and also in the arc. Completing

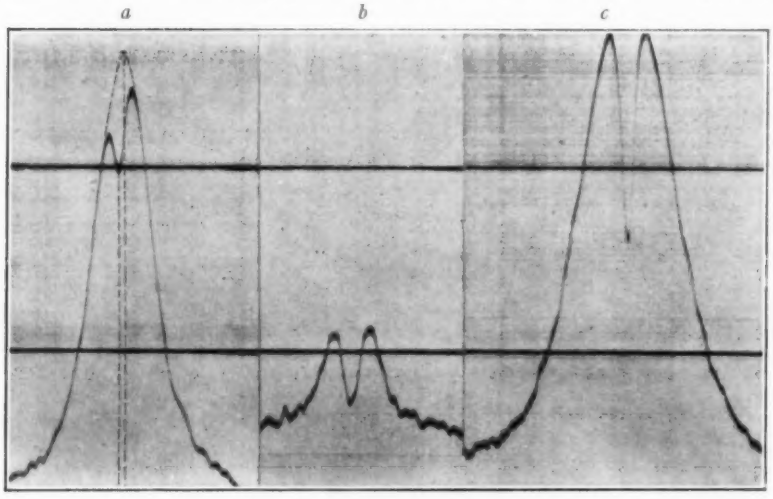


FIG. 3.—Curves of λ 3737 of iron; *a* and *b*, from middle and end of long spark line; *c*, from arc line.

the curve for the unsymmetrical spark line shows the difference between the ordinate given by this and the ordinate of the reversal, which marks the position of the line in the arc.

Both in the appearance of the reversed lines, usually moderately unsymmetrical, and in the density-curves obtained from them, there is a close correspondence between the effects for the tube-arc and the condensed spark in the case of the iron lines listed in Table I. The lines of Table II, which are very unsymmetrically reversed in the tube-arc, do not reverse in the spark on any of my plates, but are winged strongly on the red side. Typical density-curves obtained from lines of this class are shown in Fig. 4.

In contrast with these lines, the strong diffuse lines of the green-yellow, which show dissymmetry toward the violet in the iron arc and are displaced toward the violet in the tube-arc, are shaded strongly on the violet side in the spark. These lines are given relatively strong by the core of the spark and by the most intense regions of the arc.

The evidence indicates that the core of the spark radiates lines which are in general displaced toward the red, probably to different degrees according to the class of the line. Such a displaced line

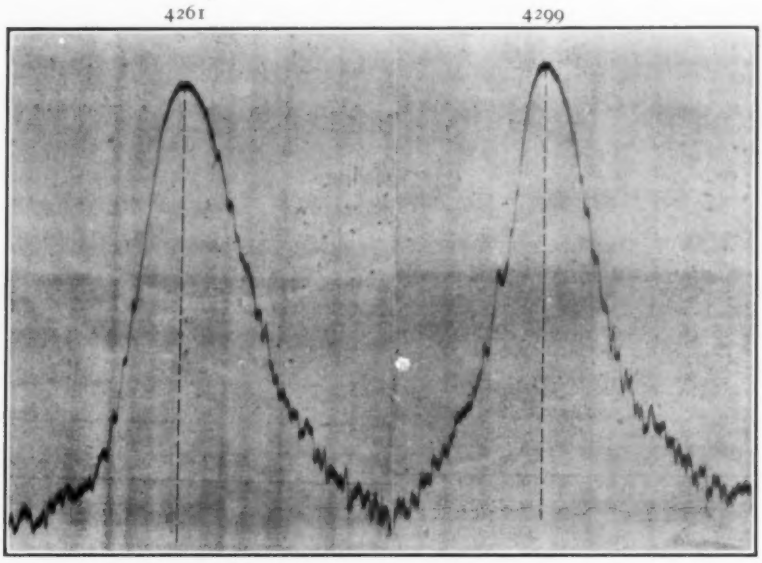


FIG. 4.—Curves of iron lines showing one-sided structure in the disruptive spark

might be symmetrical if a homogenous mass of vapor from the core of the spark could be isolated. The line usually photographed is a composite given by the superposition on this core line of less-displaced radiations from the vapor enveloping the core. The density-curves of the strong reversed iron lines of moderate dissymmetry, usually belonging to furnace Class II, indicate the presence of a symmetrical line from the core of the spark differing in wave-length from the absorption line given by the outer vapor. These lines are quite similar in the tube-arc and spark. The iron

lines at the two extremes of the furnace scale, the flame lines (Class I) and the enhanced lines (Class V E), are very nearly symmetrical in the condensed spark. It is shown, however, with the plane grating and long slit, that the flame lines are given chiefly by the outer vapor and are therefore out of the displacing region while the enhanced lines are confined to the core with no superposed radiation to render them unsymmetrical. The former should, therefore, remain symmetrical and undisplaced, while an enhanced line in the spark should be symmetrical but displaced with reference to the same line in the furnace or center of the arc. Only a few enhanced lines appear in the latter sources, however, and an accurate comparison presents many difficulties on account of the great difference in the strength of these lines in the spark and in the arc or furnace.

TUBE-ARC AND SPARK EFFECTS FOR OTHER ELEMENTS

A study in some detail has been made of the dissymmetries shown by titanium in tube-arc and spark, together with a few photographs of interesting regions in the vanadium and chromium spectra. Alloys of titanium and vanadium with iron were used to secure the highly disruptive spark. The main features observed may be briefly given.

Titanium shows a very close correspondence between tube-arc and spark in the degree to which various lines are made unsymmetrical. Among the strong reversed lines in the blue, certain groups show a decided difference in dissymmetry, this difference being alike in the two sources. λ 4298.89 is an example of symmetrical reversal, while λλ 4527.47 and 4457.61 have their sides unsymmetrical about in the degree 1:2 and 1:4 respectively. Lines of similar structure show a tendency to group in the neighborhood of these lines. While these are for the most part in furnace Class II, the more unsymmetrical lines approach the behavior of Class III lines in the furnace. The strong lines in the green near λ 5000 were examined in the condensed spark and show distinct differences in structure. λλ 4981.93 and 4991.24 show 1:2 dissymmetry while λλ 5036.08 and 5036.65 are more one-sided, about 1:4. Two

Class I lines in this region, λλ 5040.14 and 5064.79, partially reversed in the spark, are nearly symmetrical.

The enhanced titanium lines show considerable variation in the condensed spark. Those in the green are unreversed and very symmetrical in structure. Fig. 5 gives the density-curves for one of these and for a typical titanium arc line in this region. The enhanced lines from λ 3600 to λ 4600, however, are so strong in the spark that many of them are reversed, and these reversals, while usually unsymmetrical toward the red, are unsymmetrical

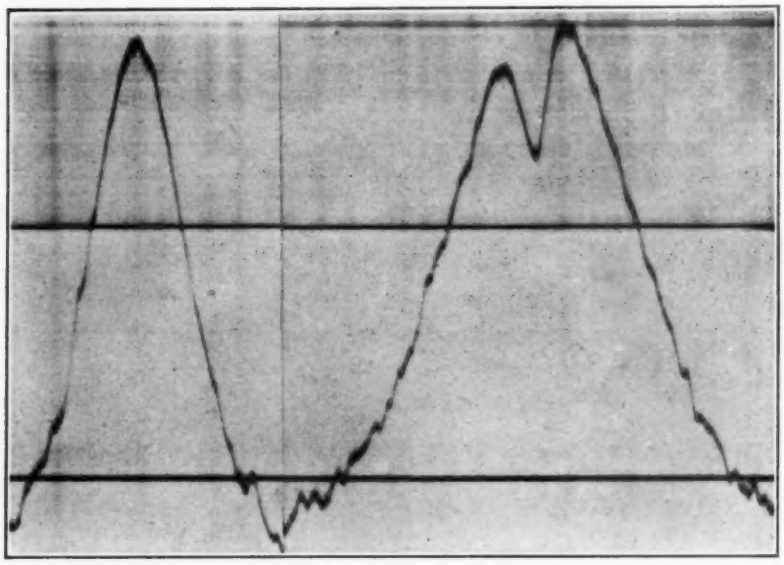


FIG. 5.—Curves of titanium lines in the disruptive spark

toward the violet for λλ 4395.19 and 4444.00. Enhanced lines showing symmetrical reversal are λλ 3685.37, 3759.46, and 3761.47.

The spark spectra of vanadium and chromium were photographed for parts of the violet, blue, and green where distinctive strong lines occur. The plates show dissymmetries of varying amounts to occur very generally, but no decided difference has been noted from the condition prevailing in the iron and titanium spectra. Class I lines of vanadium and chromium show rather larger dissymmetries than those of this class in the other spectra, but these are

very strong lines and the distribution of vapor between the core of the spark and the reversing envelope may be slightly different from that of iron and titanium lines in the same class.

COMPARISON WITH THE PRESSURE-EFFECT

It has been shown that the degree of dissymmetry exhibited by various classes of lines in the tube-arc and condensed spark corresponds closely with their susceptibility to pressure displacement. The question arises whether pressure may be active in the tube-arc and in the spark. Two lines of evidence are against this. First, the dissymmetries show no tendency to become larger with increasing wave-length, as do the pressure displacements, and, second, the tube-arc is operated in a partial vacuum, its action becoming more favorable to strong dissymmetries as the pressure is decreased. In addition to the difficulty of considering a high pressure in the ordinary sense as present in the spark in air, the resemblance of the spark effects to those of the tube-arc is so close that their causes would seem to be very similar. It will be shown later how the action of pressure may be different from that producing the tube-arc and spark displacements and yet produces equivalent effects.

THE INFLUENCE OF VAPOR-DENSITY

Examination of the tube-arc photographs and measurement of such lines as permit of it show clearly that, with the given electrical conditions, the dissymmetry of lines becomes much greater when their width is increased by the use of a large quantity of vapor. The measured displacement becomes small if the line is narrowed by the presence of only a small amount of vapor. However, the spectra given by the regular furnace offer evidence that high vapor-density alone will not render lines unsymmetrical. The writer has never yet observed a line in the furnace spectrum which was clearly unsymmetrical. To be sure, many of the lines most sensitive to this effect are in Class III or Class IV and are therefore narrow and unreversed in the furnace, but a number of strong titanium lines, very unsymmetrical in the tube-arc and spark, are reversed in the furnace at high temperature and remain quite symmetrical. The vapor-density in the furnace must be considerable,

in spite of the large volume of the tube. This is attested by the width of the stronger lines and by the fact that, during the short run required for an exposure, two grams or more of iron may be vaporized so that the tube is afterward found incrusted with it from end to end. In the arc also, lines may be very wide when much vapor is present, and still remain symmetrical. When the poles of the arc are approached, however, the occurrence of enhanced lines indicates a condition resembling the spark, and in this region the lines most sensitive to displacement become one-sided. These dissymmetries are greatly magnified in the tube-arc and in the disruptive spark.

A considerable degree of harmony among these effects is obtained if it is permissible to consider as a necessary condition the presence of electrified particles moving at high velocities. These are supplied in the spark and at the poles of the arc by the high potential gradients. The cause for the very similar spectrum effects in the tube-arc, where the potential is low, is not so clear, and at present the writer can only refer to the suggestion offered in a previous paper[1] that the heated carbon ejects electrons which are given high velocities by the explosive conditions at the point of rupture. We know that at this point there is a great concentration of electrical energy, and the effects would seem to indicate that the action of the tube-arc produces a superheating of the carbon in virtue of which the electrons are given velocities comparable with those imparted in other sources by a high potential. If this possibility is admitted, the effect of high electronic speeds in causing a disturbance of period should be increased by the crowding together due to high vapor-density, and on this account the relation to the pressure effect may be a close one. Spectrum lines from the furnace or from the center of the arc, given by particles having low velocity, are displaced by the crowding due to pressure. If the source does not have high pressure, but is such that the particles have high velocities, the tendency of these velocities to disturb the period would be expected to increase with the density of the vapor.

A consequence of this point of view would be that high pressure should give large displacements for lines which are strengthened

[1] *Mt. Wilson Contr.*, No. 73; *Astrophysical Journal*, **38**, 315, 1913.

by strong electrical conditions. This is borne out by the large pressure displacements found for lines in Classes III and IV of the furnace classification. These lines are much stronger in the arc and spark than in the furnace. Further, Gale and Adams[1] observed that the enhanced lines as a class are displaced by pressure more than the arc lines, and that for a given pressure the enhanced lines are displaced more in the spark than in the arc. They note also that when the arc and spark were observed at the same pressure, the lines in general show "a marked tendency toward higher values for the spark displacements." All of these effects would follow as a direct result of a combination of high electrical action with high pressure.

Royds,[2] in reviewing the displacement effects observed as a result of arc dissymmetries, arrives at the conclusion that vapor-density plays an important part, while recognizing the possible influence of ionization in the arc and spark, and suggests "density of ions" as a substitute for "vapor-density" as the displacing cause. I believe this idea is in the right direction and would make a further modification by suggesting *density of high-speed electrons* as a condition which appears to harmonize the results for the displacements of the arc, spark, and tube-arc with those for the pressure-effect and to account for the evident connection of all of these with the furnace classification.

SUMMARY

1. The results for the tube-arc and the disruptive spark show that these sources impart an unsymmetrical structure to many of the stronger spectrum lines, the micro-photometer indicating that this is caused by the region of strongest excitation giving a displaced line, usually to the red.

2. Much variability appears in the amount of this dissymmetry for different lines, its magnitude clearly being related to the furnace classification of the lines and to their displacement under pressure.

3. Iron lines of small and moderate dissymmetry in the tube-arc are low-temperature lines and show only moderate pressure-effect.

[1] *Mt. Wilson Contr.*, No. 58; *Astrophysical Journal*, **35**, 10, 1912.

[2] *Kodaikanal Observatory Bulletin*, No. 40, 1914.

4. Lines of large dissymmetry are faint in the furnace relatively to the arc and are greatly displaced by pressure.

5. The degree of dissymmetry in the tube-arc, for each of the foregoing classes, has a distinct relation to the width of the line, so that, other things being equal, strong lines are more displaced by this effect than faint ones and an increase of vapor-density increases the dissymmetry.

6. The most symmetrical lines of iron in the tube-arc are the "flame" lines. The H and K lines of calcium reverse with the violet side strongest.

7. Lines unsymmetrical toward the violet in the spark and near the pole of the arc are displaced toward the violet in the tube-arc.

8. The nebulous lines of iron, requiring strong arc conditions, are much intensified in the tube-arc.

9. A powerful and disruptive spark produces line dissymmetries which in general are very similar to those of the tube-arc. The most symmetrical iron lines in this spark are the "flame" lines and the enhanced lines.

10. Analysis by the plane grating shows the radiation from the core of the spark to be displaced toward the red, in the case of most of the stronger lines, the outer vapor giving a symmetrical line in the position of the arc line.

11. The results indicate that a condition of strong electrical excitation, combined with high vapor-density, produces a condition the displacing action of which shows many resemblances to the effect of pressure.

The writer wishes to acknowledge the valuable assistance of Mr. Colby and of Mr. Monk, who operated the micro-photometer in registering the curves for this investigation.

MOUNT WILSON SOLAR OBSERVATORY
April 20, 1915

AN APPARENT RELATION BETWEEN THE RADIAL VELOCITIES OF THE STARS AND THEIR MAGNITUDES

By. C. D. PERRINE

In a former paper[1] I presented evidence showing a relation between the inherent radial velocities of 225 of the brighter stars of Class B and their magnitudes, the fainter stars having the greater velocities.

The investigation has now been extended to cover the stars of Classes A, F, G, K, and M as contained in Campbell's lists published in *Lick Observatory Bulletin*, Nos. 211 and 229.

The results given below are derived from Campbell's V_2 value for the stars of Class A and similar values of the radial velocities of the other classes. For classes F, G, K, and M these values were obtained by correcting the observed velocities for the solar motion, using $\alpha = 270°$, $\delta = +30°$, $V_\odot = -19.5$ km, and $K = 0$.

In order to make the entire investigation more homogeneous new results were obtained for the stars of Class B also, using the same apex and value of V as for the other classes and ignoring K. The results are included in the following tables along with the others. These differ somewhat in detail from those published earlier, which include the effect of the K term. The dependence upon magnitude is still shown, however, although not with so large a range.

It is perhaps a question as to the best system for such an investigation—whether the exclusion of the K term represents the real velocities of the stars more accurately or not. I have found some very peculiar results of a semi-systematic nature in practically all of the classes, for groups in different parts of the sky, which make me doubt the advisability of assuming that K depends simply on spectral class or subdivision. I hope to publish the preliminary results of that investigation soon. In the meantime I prefer to treat the present investigation without any limitation in that respect.

[1] *Astrophysical Journal*, **41**, 315, 1915.

The means of the velocities by classes and magnitudes are given in Table I.

TABLE I

	B		A		F		G		K		M	
	No.	V	No.	V	No.	V	No.	V	No.	V	No.	V
1.9 and brighter	11	5.7	8	15.1	11	11.5	7	12.5	6	14.8	16	12.5
	19	8.0							5*	9.2		
2.0–2.9..	*17	6.2	19	12.2					25	12.1	*14	8.6
3.0–3.9..	43	7.3	26	8.7	28	16.3	23	13.7	87	15.3		
4.0–4.9..	152	7.9	121	10.7	161	14.9	108	13.7	309	15.9	64	18.5
5.0 and fainter.			38	12.6		.....	....	.....	....	.....	....	.....

* Rejecting one or two abnormally large velocities.

To test any possible effect of the known preference of the higher velocities for the Milky Way, the results were classified also in that respect. The result is shown in Table II.

TABLE II

Class	Magnitude	0° to ±20°		±20° to ±40°		±40° to ±90°	
		No.	Mean V	No.	Mean V	No.	Mean V
			km		km		km
B.....	2.9 and brighter..	24	7.5	1	4.9	5	6.1
	3.0 and fainter....	132	8.1	33	8.4	26	4.1
Ap.....	2.9 and brighter..	2	22.1	0	.....	3	4.3
	3.0 and fainter....	1	14.8	4	7.4	5	5.3
A.....	2.9 and brighter...	7	16.1	2	7.0	3	8.3
	3.0 and fainter....	21	10.8	16	10.2	34	9.3
A1–A3...	2.9 and brighter...	3	22.9	1	0.6	3	8.9
	3.0 and fainter....	21	12.2	12	13.8	27	8.8
A5–A8...	2.9 and brighter...	2	14.6	0	.....	1	4.9
	3.0 and fainter....	16	13.2	5	8.7	23	13.1
F.....	2.9 and brighter...	8	13.6	2	7.3	1	2.8
	3.0 and fainter....	65	15.9	35	17.8	84	13.4
G.....	2.9 and brighter...	3	17.9	0	.....	4	8.5
	3.0 and fainter....	46	26.5	32	29.2	60	16.0
K.....	2.9 and brighter...	15	11.7	9	10.9	8	23.2
						6	13.0*
	3.0 and fainter....	156	17.8	103	19.4	152	16.5
M.....	2.9 and brighter...	3	9.4	2	9.5	2	18.6†
	3.0 and fainter....	16	19.5	17	17.4	35	15.4

* Rejecting two large values of 68.7 km and 38.4 km.

† The individual values are 35.7 km and 1.5 km.

Finally the results were generalized by combining all results into two classes of magnitude, viz., 2.9 and brighter, and those of 3.0 and fainter. The results are given in Table III.

TABLE III

Class	2.9 and Brighter	3.0 and Fainter
	km	km
B	6.6	7.6
A	12.5	10.8
F	11.5	15.6
G	12.5	13.7
K	12.0	15.6
M	10.6	18.5
All	11.0	13.6

As a further test of the reality of this dependence upon magnitude, the velocities of the B stars in the region of sky from 10^h to 14^h were tabulated. As these stars are practically all in the Milky Way and the center of this region at 90° from the apex, the result should be almost entirely free from systematic errors depending upon uncertainties in the velocity and direction of motion of the observer and from the effect of large or small systematic velocities in different regions of the sky, should the distribution not be essentially uniform. The result is given in Table IV.

TABLE IV

	No. of Stars	*V*
		km
1.9 and brighter	5	5.3
2.6–3.3	6	6.7
4.0 and fainter	20	10.1

The increase of velocity with decrease of brightness is clearly exhibited in all classes except A, where the reverse seems to be true. The stars for that class were arranged, not only with respect to the galaxy, but also with respect to the spectral subdivisions. This classification showed that the apparent exception was only in the stars of the galaxy—all of the A stars in other parts of the sky conforming to the condition observed in the other classes, notwithstanding the small number in each compartment.

In the galaxy, however, all the subdivisions show a decidedly higher velocity for the brighter stars than for the fainter ones. This can hardly be mere coincidence even in such meager data, and probably indicates a real tendency and not simply an accidental accumulation of high velocities, although it is to be noted that in the stars of Classes F, G, and K, where large velocities as well as quite small ones are frequent, it is not difficult for accidental accumulation in small groups to form apparent exceptions. Such a case probably is that of the stars of magnitude 3.0–3.9 in Class F.

It is to be observed that the bright galactic A stars show velocities much higher than the brighter stars of the other classes, whereas the fainter galactic A stars fall in the progression according to class.

A possible explanation of this apparent abnormality is that these stars have acquired high velocities under some exceptional condition, for they are considerably higher than the average fainter stars of the same class. Another explanation which satisfies the condition, provided the increase of velocity with decrease of brightness extends also to fainter magnitudes than those at present observed, is that some such stars have wandered sufficiently near to appear relatively bright.

CONCLUSIONS

The foregoing investigation strongly indicates a dependence of the inherent radial velocities of the brighter stars of Classes B, A, F, G, K, and M upon magnitude.

The stars involved number 1309, over half of the total number of stars of magnitude 5.5 and brighter, and therefore give confidence of representing the real conditions existing among such stars.

Strong corroboration of this conclusion is found in the fact that the highest velocities are found only among the fainter stars, not a single instance to the contrary being known.

Of the 38 stars in the list having velocities of 50 km and over, only one is as bright as magnitude 2.4 and four are between 3.0 and 4.0. There are five stars of 100 km and over, the brightest of which is of magnitude 5.2—the mean magnitude of the five being 6.9.

As the stars of greatest known velocities are below the visible magnitudes, it seems reasonable to suppose that an increase of velocity may also continue with decrease of magnitude below the fainter limit of this investigation.

The magnitude-velocity equation appears to increase in the stars of later type.

Campbell concluded[1] from his investigations that the radial velocities increase toward the galactic plane, especially among the stars of earlier class. My own investigations tend to confirm that conclusion. The greatest velocities among the fainter stars of Classes F, G, and K appear to be on the edges of the Milky Way rather than near its central line.

The highest velocities known show a decided preference for the Milky Way. Seventy-five per cent of the velocities of 50 km and over are within 40° of the galactic plane and 40 per cent are within 20°. All five stars having velocities over 100 km are within 40° of the galactic plane.

The cause of such a dependence upon magnitude may be complicated or obscure, but at first sight it seems most likely to result from one of two causes, viz.: (*a*) a difference in size or density, or both, in conjunction with some form of resisting medium; (*b*) that the fainter stars are those which are farther away from the observer and nearer to a source of general gravitational action. That the Milky Way is deeply concerned in either case seems probable.

Here again, as in almost all other problems relating to the arrangement of the universe of stars, we need more complete knowledge of their distances and masses. An investigation of these conditions should aid materially in explaining the cause of this dependence upon brightness.

OBSERVATORIO NACIONAL ARGENTINO
CÓRDOBA
March 17, 1915

[1] *Lick Observatory Bulletin*, No. 196, p. 130.

Minor Contributions and Notes

A SENSITIVE PHOTO-ELECTRIC CELL

Many investigations require a sensitive photo-electric cell equipped with a quartz, or fluorite, window. The most sensitive cells are those in which the photo-electric metal is a layer of sodium, or potassium, prepared by distilling *in vacuo*. Descriptions of methods of preparation of this type of cell have been given by Hughes[1] and by Ives,[2] but it is believed the following method is more simple and easier to carry out.

A glass bulb 4 cm in diameter is blown, with three side-tubes *A*, *B*, and *C* (Fig. 1). A brass wire is sealed in *B*, and from *B*

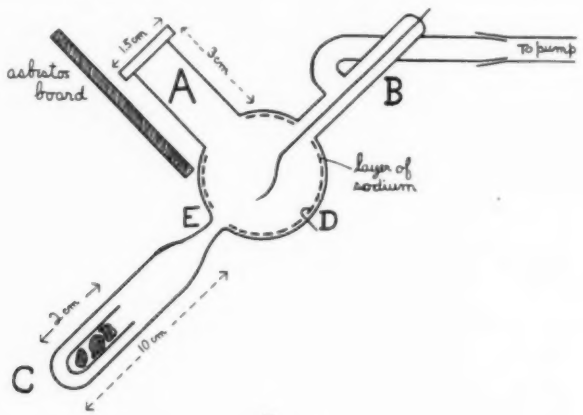


FIG. 1

a side-tube leads to the pump through a ground-glass joint, so that the whole cell may be rotated. On *A* is sealed the quartz (or fluorite) window with red sealing-wax. *D* is a platinum electrode, bent over until it touches the interior of the glass surface, to insure contact with the layer of sodium. The cell is thoroughly cleaned with chromic acid and alcohol, and dried. A small glass capsule is

[1] *Phil. Mag.*, **25**, 679, 1913.

[2] *Astrophysical Journal*, **39**, 428, 1914.

stuffed full of clean metallic sodium (of course covered with the oxide) and this capsule is then placed in the tube *C*, which is thereupon sealed off. The cell is then connected to the pumps by means of the ground-glass joint and is exhausted. With the tube *A* vertically upside down, so that the quartz window may be immersed in water, the whole cell is heated all over with the flame of a small blast-lamp as hot as advisable (too hot to touch). The pumps are running all the while to take away any gases which may be driven from the glass surface, and the cell is then allowed to cool. When cool it is rotated into the position shown in Fig. 1. The quartz window is protected now by an asbestos shield and is kept cool by a wad of wet cotton. By a careful manipulation of the small blast-lamp,the sodium is distilled up through the constriction *E* (which must be of even thickness, and well annealed), and soon the whole interior of the bulb is covered with a layer of sodium. A glance into the cell shows that the interior is covered with a beautiful deposit in the form of white droplets. When the layer is fairly opaque to transmitted light enough sodium has passed over, and the distillation is stopped.

During the distillation *E* must be kept very hot, but care must be taken that no sodium vapor condenses on the quartz window. The pumps must be running during the entire process, for the sodium gives off hydrogen in large quantities. The constriction *E* must finally be heated enough to clean the glass entirely of any sodium, and then the tube *C* may be sealed off. Unless *E* is clean, the seal will surely crack upon cooling. Finally the cell is sealed off from the pumps. This method yields an extremely sensitive cell.

E. O. HULBURT

JOHNS HOPKINS UNIVERSITY
May 7, 1915

THE SPECTRAL DISTRIBUTION OF THE STARS OF LARGE RADIAL VELOCITY

In classifying the stars for various purposes, it was noticed that the largest radial velocities appeared to be in Classes F, G, and K. It became of interest and of importance in properly interpreting

certain relationships to examine the distribution of these very high velocities. Table I exhibits the principal results of that investiga-

TABLE I*

	B	A	F	G	K	M
Total stars	225	212	200	153	443	80
No. of stars, 50 km and over	0	0	3	16	16	4
No. of stars, 50 km and over per 100	0	0	1.5	10.5	3.6	5.0
Mean velocity	.....	.....	99.6km	91.5km	71.4km	55.6km
Mean magnitude	.....	.....	6.1	5.4	4.3	4.4
No. of stars, 100 km and over	0	0	1	3	1	0
Mean velocity,† all stars in class	7.7km	11.0km	14.9km	21.4km	17.5km	17.3km

* Compiled from Campbell's catalogues.

† Corrected for solar motion of −19.5 km and $K=0$.

tion. This tabulation shows that the largest number of great velocities, the greatest velocities, and the highest average for the large velocities occur in stars of Classes F and G.

This result from 1300 stars almost certainly represents correctly the general tendency in the naked-eye stars and probably in the stars to eighth or ninth magnitude as well.

Table II shows the result of additional velocities determined at Mount Wilson from stars having large proper motions and published in the *Mt. Wilson Contr.*, Nos. 59 and 79. Only those stars having velocities of 50 km and over are included. These results

TABLE II

	B	A	F	G	K	M
No. of stars	0	2	4	6	3	1
Mean magnitude	.....	7.6	7.2	6.4	6.5	7.6
Mean velocity	.....	154 km	178 km	64 km	54 km	85 km

tend to confirm the conclusion already arrived at, but to place the highest velocities rather earlier in the spectral scale. It is not, of course, contended that the numerical results are more than approximate. All recent investigators have shown that the stars of Classes

F and G have the largest average proper motions and are the nearest to us. The conclusion from this is that the average stars of Classes F and G, solely because of their nearness, appear brighter to us than the average stars of any other class of the same size or absolute brilliancy.

The finding of the maximum of radial velocities among the faint stars of Classes F and G tends still further to confirm the conclusion that the radial velocities, and probably the total velocities, are functions in general of the brightness of the stars and possibly also of their sizes or masses.

C. D. PERRINE

OBSERVATORIO NACIONAL ARGENTINO
CÓRDOBA
April 7, 1915

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The scope of the ASTROPHYSICAL JOURNAL includes all investigations of radiant energy, whether conducted in the observatory or in the laboratory. The subjects to which special attention is given are photographic and visual observations of the heavenly bodies (other than those pertaining to "astronomy of position"); spectroscopic, photometric, bolometric, and radiometric work of all kinds; descriptions of instruments and apparatus used in such investigations; and theoretical papers bearing on any of these subjects.

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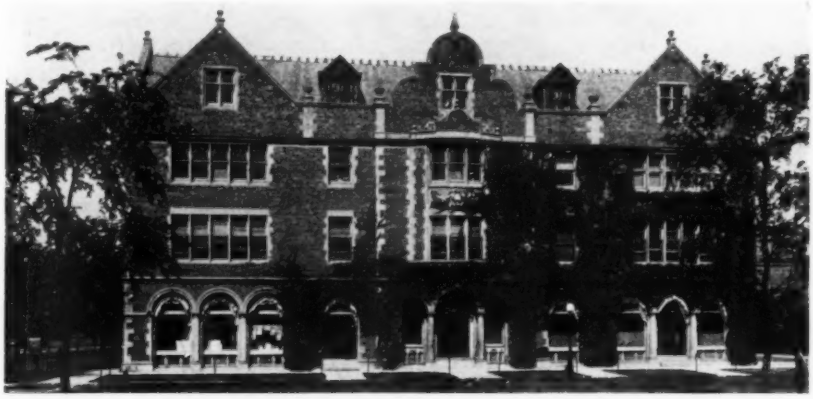

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THE SUMMER QUARTER

AT

THE UNIVERSITY OF CHICAGO

1915

THE Summer Quarter at the University of Chicago is the most largely attended of the year, nearly four thousand students having registered in the summer of 1914. The University year is divided into quarters: the Autumn, Winter, Spring, and Summer, and students are admitted at the opening of each quarter, and also in certain designated courses at the beginning of the second term of the Summer Quarter.

The courses during the Summer Quarter are the same in character, method, and credit value as in other quarters of the year. Students may enter for either term or both. The quarter will begin on June 21 and end September 3.

A large proportion of the regular Faculty of the University, which numbers about three hundred and fifty, and also many instructors from other institutions offer courses in the Summer Quarter, and in this way many varied points of view are given to students in their chosen fields of study.

ARTS, LITERATURE, AND SCIENCE

The University offers during this quarter, in the Schools of Arts, Literature, and Science, both graduate and undergraduate courses in Philosophy, Psychology, and Education; Political Economy, Political Science, History, Sociology and Anthropology; Household Administration; Semitics; New Testament Literature; Comparative Religion; History of Art, Sanskrit, Greek, and Latin; Modern Languages; Mathematics, Astronomy, Physics, and Chemistry; Geology, Geography, and Paleontology; Botany, Zoölogy, Physiology, Anatomy, Pathology, Hygiene and Bacteriology; Public Speaking; Music.

THE PROFESSIONAL SCHOOLS

Education

In the Professional Schools the Graduate Department of Education in the School of Education gives advanced courses in Principles and Theory of Education, Educational Psychology, the Psychology of Retarded and Subnormal Children, History of Education, and Social and Administrative Aspects of Education. The College of Education is a regular college of the University, with all University privileges, and in addition provides the professional training of elementary- and secondary-school teachers and supervisors. It offers undergraduate courses in professional subjects and in the methods of arranging and presenting the various subject-matters which are taken up in the elementary and secondary schools. The University High School, with the fully equipped shops of the Manual Training School, is in session during the Summer Quarter, and opportunity is offered to take beginning courses in Latin and German and to review courses in Mathematics and History. The regular shop work supplemented by discussions of methods is open to teachers pursuing these courses.

Divinity

The Divinity School is open to students of all denominations, and the instruction is intended for ministers, missionaries, theological students, Christian teachers, and others intending to take up some kind of religious work. The English Theological Seminary, which is intended for those without college degrees, is in session only during the Summer Quarter. The Graduate Divinity School is designed primarily for college graduates. Pastors, theological teachers, students in other seminaries, and candidates for the ministry with requisite training are admitted in the Summer Quarter.

Law

In the work of the Law School the method of instruction employed—the study and discussion of cases—is designed to give an effective knowledge of legal principles, and to develop the power of independent legal reasoning. The three-year course of study offered constitutes a thorough preparation for the practice of law in any English-speaking jurisdiction. By means of the quarter system students may be graduated in two and one-fourth calendar years. Regular courses of instruction counting toward a degree are continued through the Summer Quarter. The courses

are so arranged that students may take one, two, or three quarters in succession in the summer only, before continuing in a following Autumn Quarter. The summer work offers particular advantages to teachers, to students who wish to do extra work, and to practitioners who desire to study special subjects.

Medicine

Courses in Medicine constituting the first two years of the four-year course in medicine of Rush Medical College are given at the University of Chicago. For the majority of students taking up medical work for the first time, it is of decided advantage to enter with the Summer or the Autumn Quarter. For the student who is lacking in any of the admission courses, or who seeks advanced standing, it is of especial advantage to enter for the Summer Quarter. All the courses offered are open to practitioners of medicine, who may matriculate as unclassified or as graduate students. Practitioners taking this work may attend the clinics at Rush Medical College without charge

Commerce and Administration

The work of the College of Commerce and Administration for the Summer Quarter, 1915, is grouped as follows:

I. The Trade and Industry Division, where the courses are arranged with reference to the needs of those who expect to engage in the various business pursuits such as accountancy, banking, brokerage, foreign trade, insurance, etc. For purposes of convenience in administration, secretarial work and commercial teaching are classified in this division of the College.

II. The Charitable and Philanthropic Service Division, for those expecting to serve in charitable organizations, playground work, settlement work, child-welfare agencies, civic organizations, social research, etc.

The University of Chicago is peculiarly fortunate in its environment in summer. The city of Chicago is relatively cool. High temperatures are not frequent nor long continued, and the normal temperature, in comparison with that of other large cities, is low. Reports of the United States Weather Bureau show that the average summer temperature of Chicago is lower than that of most cities of its class. In addition to this advantage in weather conditions, the University has an especially favorable situation in the city. To the south stretches the Midway Plaisance, an avenue of lawn a block wide and a mile long; and about equidistant are Washington Park, a large recreation

ground on the west, and Jackson Park, equally spacious, on the shore of Lake Michigan, to the east.

Opportunities for diversion are numerous. In Jackson Park there are golf links, and in both Jackson and Washington parks, lagoons for rowing. There are many tennis courts in both parks, along the Midway, and on the campus. Through the Frank Dickinson Bartlett Gymnasium and the Lexington Gymnasium full facilities for physical culture are given to both men and women. In the Bartlett Gymnasium there is a swimming-pool open daily to men, and at designated hours in the week, to women. The Reynolds Club offers social privileges to men, membership being open to all men in the University. Special attractions at the University are the beautiful William Rainey Harper Memorial Library, with its great reading-room and book collections open to the student, the new Julius Rosenwald Hall, devoted to the Departments of Geology and Geography, the new Classics Building, one of the most artistic academic structures in the country, and the athletic field of the University, with its splendid concrete grandstand seating nearly 10,000 people.

Notable public libraries and museums, highly organized industrial plants, many typical foreign colonies, a large number of settlements, and other significant social institutions make Chicago a peculiarly appropriate center for study and investigation.

A series of public lectures in Literature, History, Sociology, Science, Art, Music, etc., scheduled at late afternoon and evening hours throughout the Summer Quarter, affords an opportunity to students and other members of the University community to hear speakers of authority and distinction in many departments of study and activity. This program will include a number of popular readings and recitals, a series of open-air plays, a series of evening concerts, and excursions to places and institutions of interest in and near Chicago.

The complete ANNOUNCEMENT of courses for the Summer Quarter of 1915 is issued in March, and may be obtained by application to

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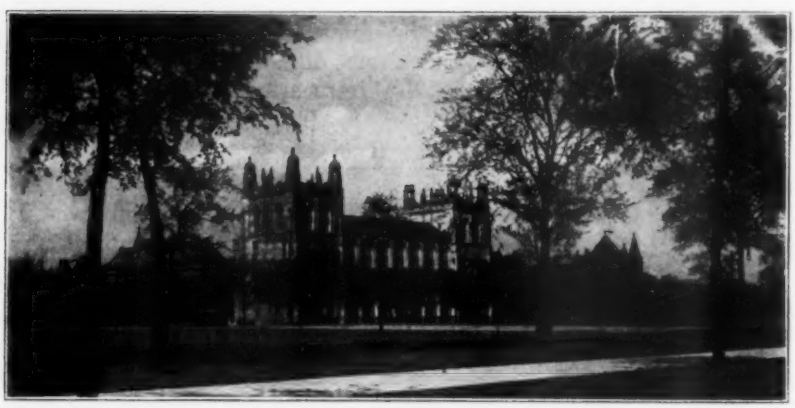

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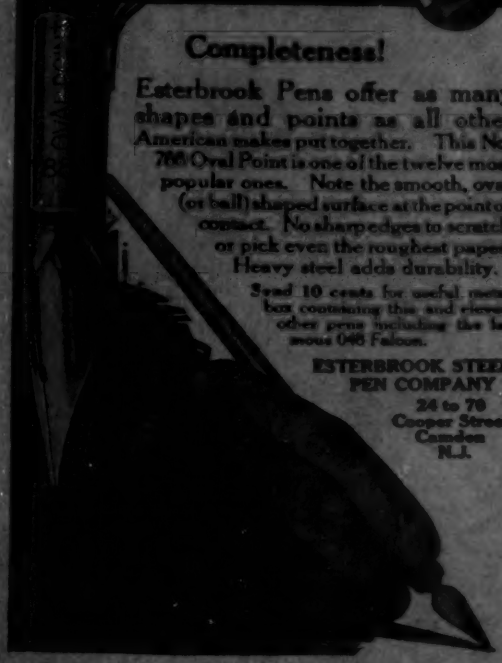

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